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June 25, 2018

Kelly Zylstra, P.E.
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Waukesha, WI 53187

Subject: Great Lakes Water Supply Program
Task 5-120 D1 Distribution System Evaluation and Improvement Identification
Technical Memorandum
GWA PM DEL 050

Dear Ms. Zylstra:

In accordance with Task 5-120 Distribution System Improvements of our Agreement, we are hereby delivering via the Great Water Alliance SharePoint site a draft of Deliverable 5-120 D1 Distribution System Evaluation and Improvement Identification Technical Memorandum.

The purpose of this technical memorandum is to document the performance of WWU's existing system under current demands to establish a baseline of performance and then document the analysis for the supply integration for each connection point and operational configuration. This model was used to evaluate connection point alternatives and to evaluate the existing and future needed storage of the distribution system and improvements needed for existing and future average day and maximum day demand conditions. The model was also used to determine control strategies at the various facilities and recommendations for phasing of needed improvements throughout the system for the new water supply.

The model will be used to finalize the design of the improvements and can also be used in future analysis to optimize system performance and capital improvement project planning.

Yours very truly,

Greeley and Hansen LLC

[redacted]

Catharine M. Richardson, P.E.
Deputy Program Manager

CMR/lam
Encl (1): Deliverable 5-120 D1 Distribution System Evaluation and Improvement Identification Technical Memorandum (electronic version)
cc: Deliverable 5-120 D1 file

Great Lakes Water Supply Program

GREAT WATER ALLIANCE

DRAFT

5-120 D1 Distribution System Evaluation and Improvement Identification Technical Memorandum

June 2018

Waukesha Water Utility
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EXECUTIVE SUMMARY

The Waukesha Water Utility (WWU) developed a computerized hydraulic model of its water distribution system to use for system analysis and evaluation. This hydraulic model is updated periodically as new pipelines are constructed as capital improvements and the operational strategy within the distribution system changes. As part of the effort for the Great Water Alliance (Program), the existing WWU hydraulic model was updated to reflect current conditions, capture planned improvements, and to identify any additional system improvements and recommendations for system operation that support the integration of a new water supply. This model was used to evaluate four different connection point alternatives for the new water supply to determine which connection point alternative resulted in the best fit for the distribution system in terms of the distribution system performance and operation. Using the preferred connection point alternative, the model was then applied with current and future demand conditions to evaluate the existing and future needed storage of the distribution system and improvements needed for existing and future average day and maximum day demand conditions. The model was also used to determine what controls were needed at the various facilities and recommendations for phasing of needed improvements throughout the system for the new water supply. A final recommendation is given for the preferred connection point operations and needed improvements to support the integration of the new water supply.

SECTION 1 Introduction

As part of the Program, conveyance improvements were identified to deliver a new water supply to Waukesha. In addition to the conveyance improvements for delivering the new water supply to the WWU system, improvements and operational changes within the distribution system were also developed and identified by assessing the potential connection point options for delivery of the new supply into the WWU distribution system. The purpose of this technical memorandum is to document the performance of WWU's existing system under current demands to establish a baseline of performance and then document the analysis for the supply integration for each connection point and operational configuration. The differences in the distribution system improvements requirements for each connection point and operational configuration are presented and recommended improvements are identified. The system assessment included analysis under projected future demands as well as an interim condition to identify how improvements could be phased in construction. A storage analysis was also included in the evaluation to identify the volume of storage needed in the WWU system in the future and which ground storage tank facilities could meet this storage need and should be maintained. The ground storage and pump station facilities will be needed to meet peak hour demands and then be refilled during the low demand periods each day. This operation of using the ground storage at well supply sites for meeting diurnal (peak hour demands) and refilling during daily lower demand periods is a change in operational strategy for WWU and needed to be defined to support baselining the delivery of flow from the new water supply, especially during peak demand times.

SECTION 2 Demand Conditions

Both existing and Approved Diversion (future) demands were considered for the evaluation of the connection alternatives. The existing demands and system configuration was evaluated under existing operating conditions to establish a performance baseline and then for each connection alternative to identify if any improvements were immediately needed. The future demand condition was evaluated to identify what additional improvements were needed to meet future projected demands with each of the connection alternatives. Table 2-1 provides a summary of the existing and future water demands considered for the connection point analysis. The maximum day demand (MDD) condition is 1.66 times the average day demand (ADD). This MDD:ADD factor was established in the Diversion Application deemed approvable by Wisconsin DNR and used as the basis for Regional review and approval.

Table 2-1. Summary of Demand Conditions for Connection Evaluation

Time Period	Average Day Demand (mgd)	Maximum Day Demand (mgd)
Existing	6.6	10.8
Future	8.2	13.6

For the demands shown in Table 2-1, the development of the future projected demand was based upon the approved diversion rate defined in the Compact Council Final Decision. It is anticipated that this projected future level of water demand would be reached in approximately 2050. As noted in Technical Memorandum 5-110 D1 Model Update and Calibration Technical Memorandum, the existing demand was updated with allocation of recent water billing data and scaled to production levels. To increase the existing demand allocation to the approved future demand condition, areas where additional growth may occur was identified by WWU and demand was scaled in this area to represent the increase in potential demand. The existing demand in other areas was scaled proportionally to align with approved future projections. Modeling and the development of system improvements is demand driven, so it is important to show demand increases in areas where they have the highest potential to occur. This was done with WWU by identifying areas within each Pressure Zone within the system where development would most likely occur, identifying the level of demand growth within each of those designated areas, and then scaling the ADD and MDD from existing to approved future demand evenly across the nodes within those development zones. Table 2-2 shows the pressure zones identified where the approved future demand was added.

Table 2-2 Pressure Zones Identified for Approved Diversion Demand Allocation

Pressure Zone	Approved Diversion Demand Allocated – ADD (mgd)	Approved Diversion Demand Allocated – MDD (mgd)
Central	0.32	0.56
Oakmont	0.32	0.56
Northwest	0.32	0.56
Pebble Valley	0.32	0.56
Reduced Northwest	0.32	0.56

SECTION 3 Existing System Operation and Performance

The WWU distribution system is currently supplied by wells in a distributed supply configuration. All supply is delivered into the Central Pressure Zone where pressure is maintained by the Hillcrest Reservoir. Supply is then pumped through a series of pump stations into higher hydraulic gradient pressure zones from the Central Pressure Zone, and the majority of the higher pressure zones operate with water towers to maintain pressure in those higher pressure zones and to control the pump station operation into those zones. With the change in supply configuration under the GWA program, supply will be delivered to the Central Zone in one location, so the greatest impact of change in operation will be within the Central Pressure Zone. Analysis of the existing system operation and performance was conducted to set a baseline for system performance in terms of minimum/maximum pressure, meeting fire flow requirements, and water age to compare with the supply integration options for each of the connection points. The current system configuration is shown in **Figure 3-1**, including recently constructed improvements as well as improvements that are planned for construction in 2018 and 2019. The existing system performance is summarized in the following sections.

3.1 Existing System Pressure

Pressure for the existing system was evaluated under a diurnal demand condition for MDD conditions and the results of the minimum pressure during the peak hour condition under the existing MDD are shown in **Figure 3-2**. The minimum pressure at any time during the existing MDD scenario are shown in **Figure 3-3**. The minimum pressures shown in **Figure 3-3** do not necessarily occur at the same time as shown in **Figure 3-2**. The distribution of minimum pressures are shown in **Figure 3-4**, and includes all junctions in the model, not just demand junctions. The evaluation of minimum pressures for the MDD scenarios shows that areas of high elevation in the Central Pressure Zone near the Northwest Pressure Zone border and near the Madison Booster Pump Station exhibit low pressures. Low pressures are also predicted at areas of higher elevation in the Central Pressure Zone in the southeast portions of the Central Pressure Zone.

3.2 Existing System Fire Flow

Fire flow requirements for the WWU system were established based upon Waukesha zoning designations across the WWU system, and the fire flow requirements are summarized in **Table 3-1**. These fire flow requirements were confirmed to be defined in the hydraulic model at hydrant locations, and **Figure 3-5** shows the fire flow requirements spatially across the WWU system. The fire flow analysis with the hydraulic model provides multiple options for reviewing and analyzing fire flow results. The hydraulic model is especially useful in assessing fire flow since the hydraulic model limits the available fire flow by maintaining a defined residual pressure (typically 20 psi) across the distribution system and not just at the fire flow location. This approach is contrasted with conducting field tests for fire flow which primarily use only an adjacent hydrant to assess residual pressure and therefore provide only local influence to predicting available fire flow.

Table 3-1. Fire Flow Requirements by City Zoning

City Zoning	Fire Flow Requirement (GPM)
Residential	1,000
Two-Family (Duplex/Attached) Residential	1,750
Multi-Family	2,500
Public	3,500
Industrial	3,500
Agriculture/Environmental	500

The results of the fire flow analysis of the existing system are presented in Figures 3-6 through 3-8. Figure 3-6 shows the available fire flow when 20 psi is maintained throughout the system, Figure 3-7 shows the residual pressure at the flowing hydrant when the required fire flow is delivered, and Figure 3-8 shows the deficit to the required fire flow when maintaining 20 psi throughout the system. The areas in Figure 3-8 provide the information on the level of fire flow deficiency across the system. Based upon the results in Figures 3-6 through 3-8, the majority of areas that have fire flow deficiency fall into 3 categories: smaller diameter/older mains, dead ends, high elevation areas in the Central Zone.

In the areas of the smaller diameter, 6-inch mains, hydrants that are closer to intersections with other pipes can provide higher flows and do not show a fire flow deficiency since there is less headloss in the shorter sections of 6-inch pipe. Similarly, the dead-end pipes have elevated headloss and the deficiency is driven by localized headloss. For the areas of high elevation, the pipes have capacity to deliver the required fire flow but the flow is limited by nearby high elevation areas that fall below 20 psi with higher flow to adjacent areas during a fire flow event.

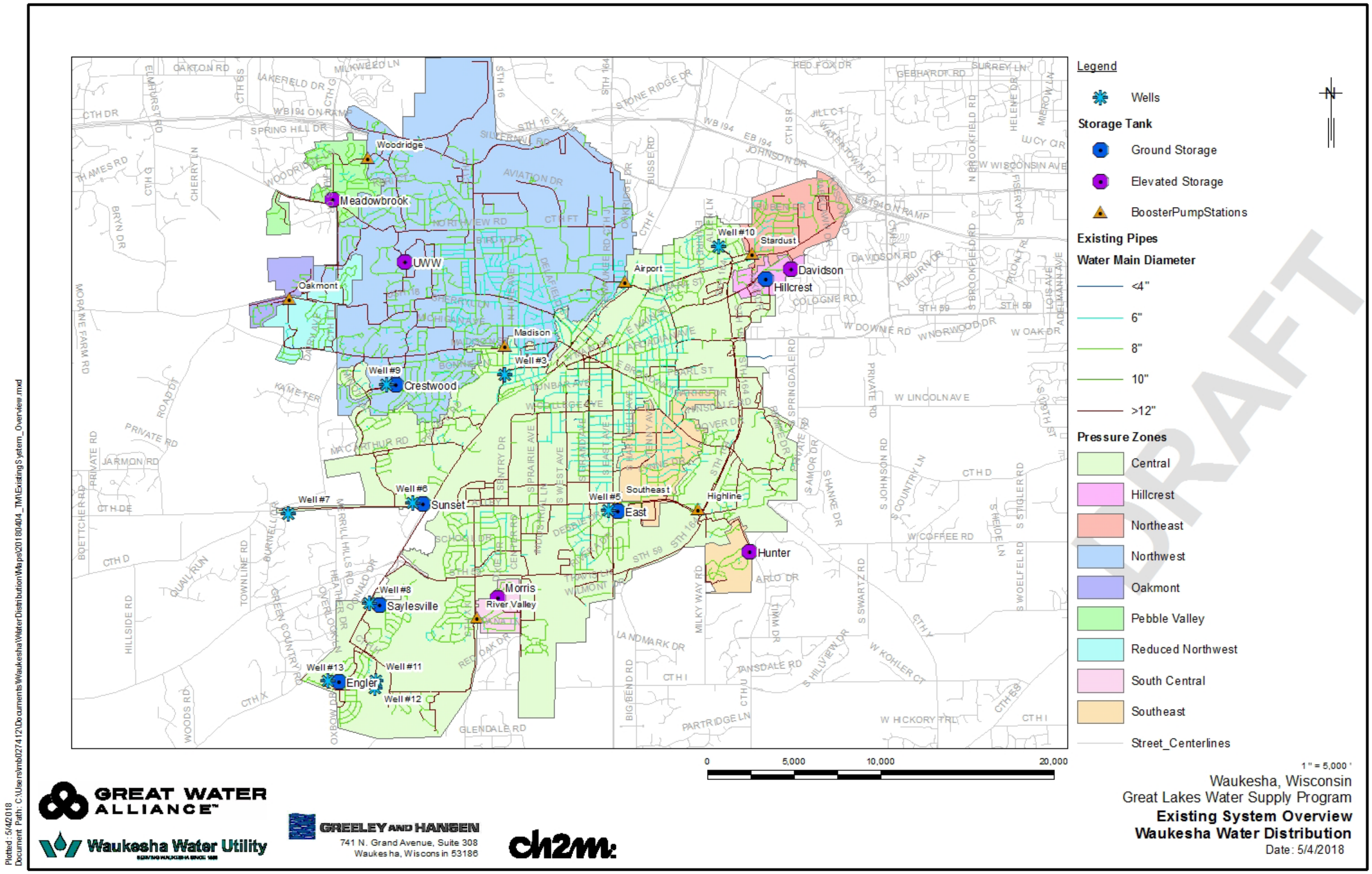


Figure 3-1. Existing System Overview

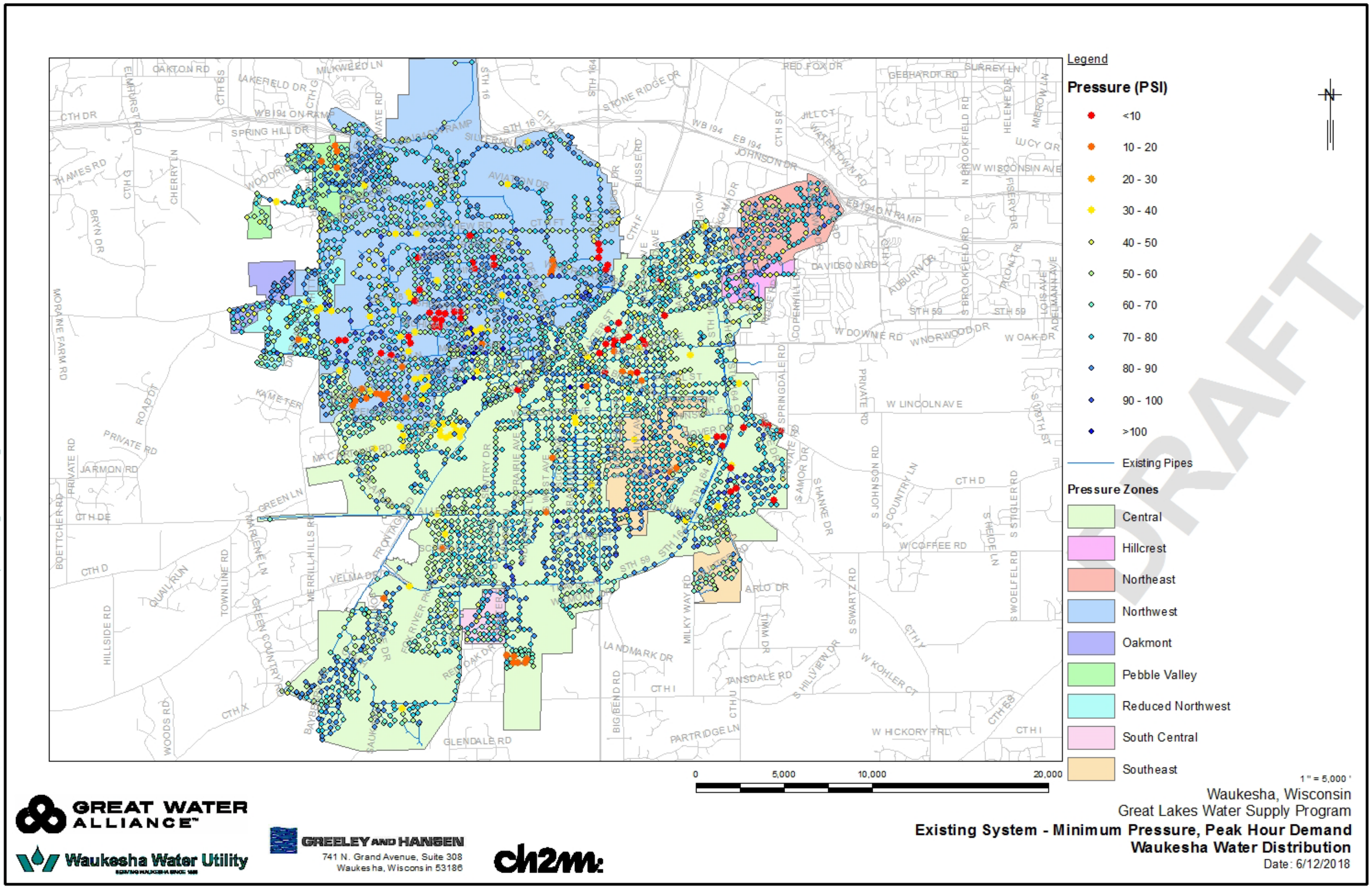


Figure 3-2. Minimum Pressure for Peak Hour Demand

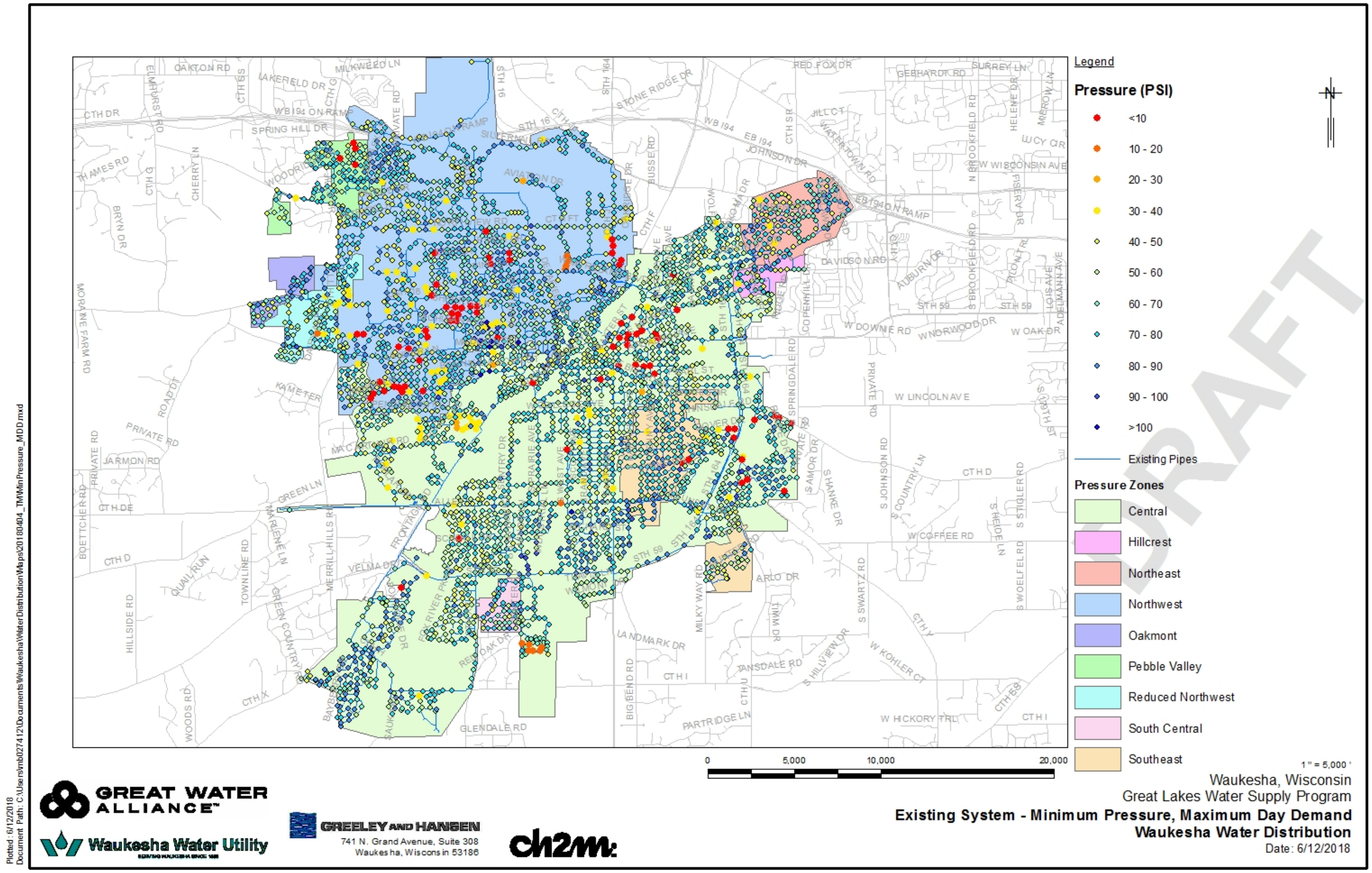


Figure 3-3. Minimum Pressure during MDD Simulation

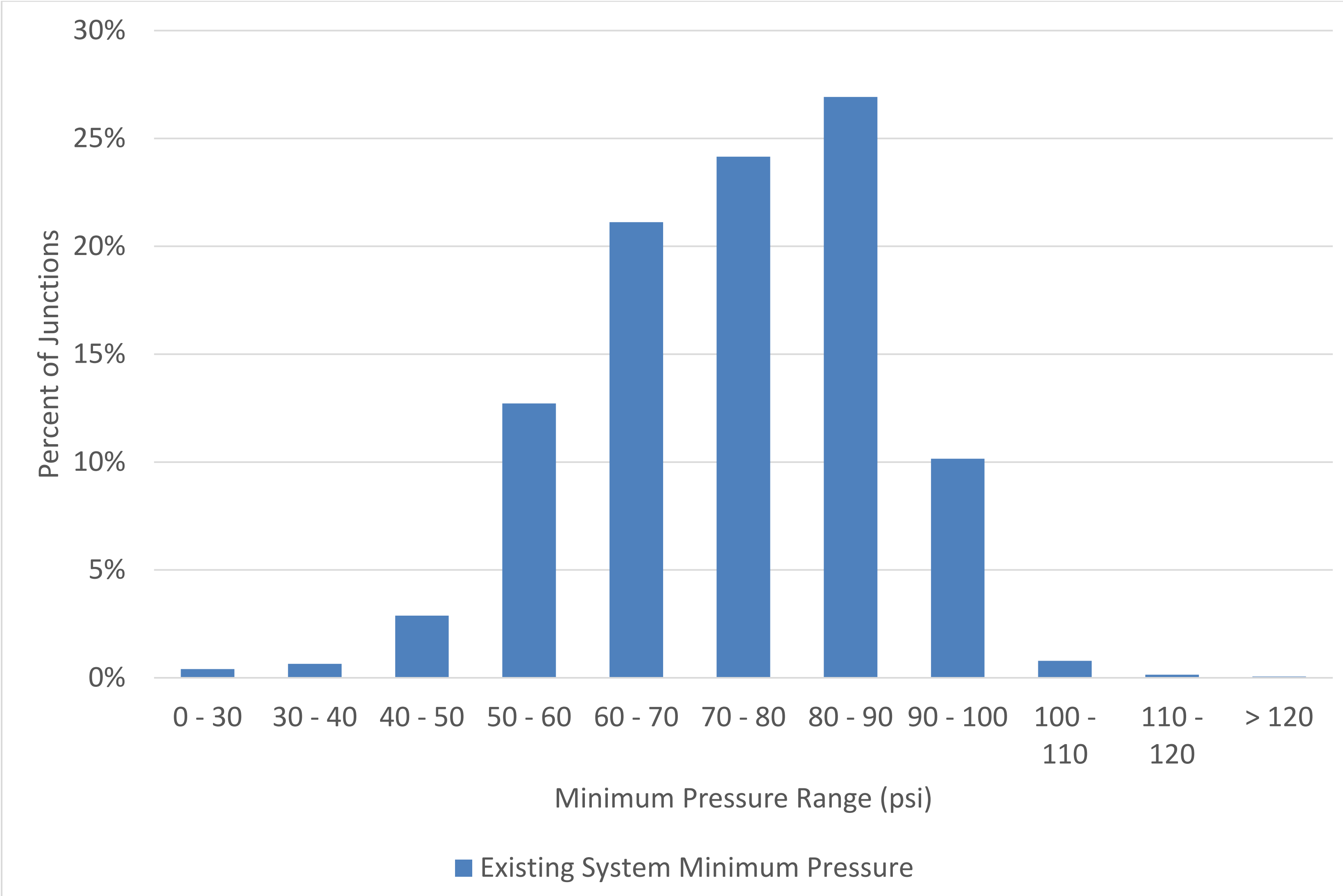


Figure 3-4. Minimum Pressure Distribution

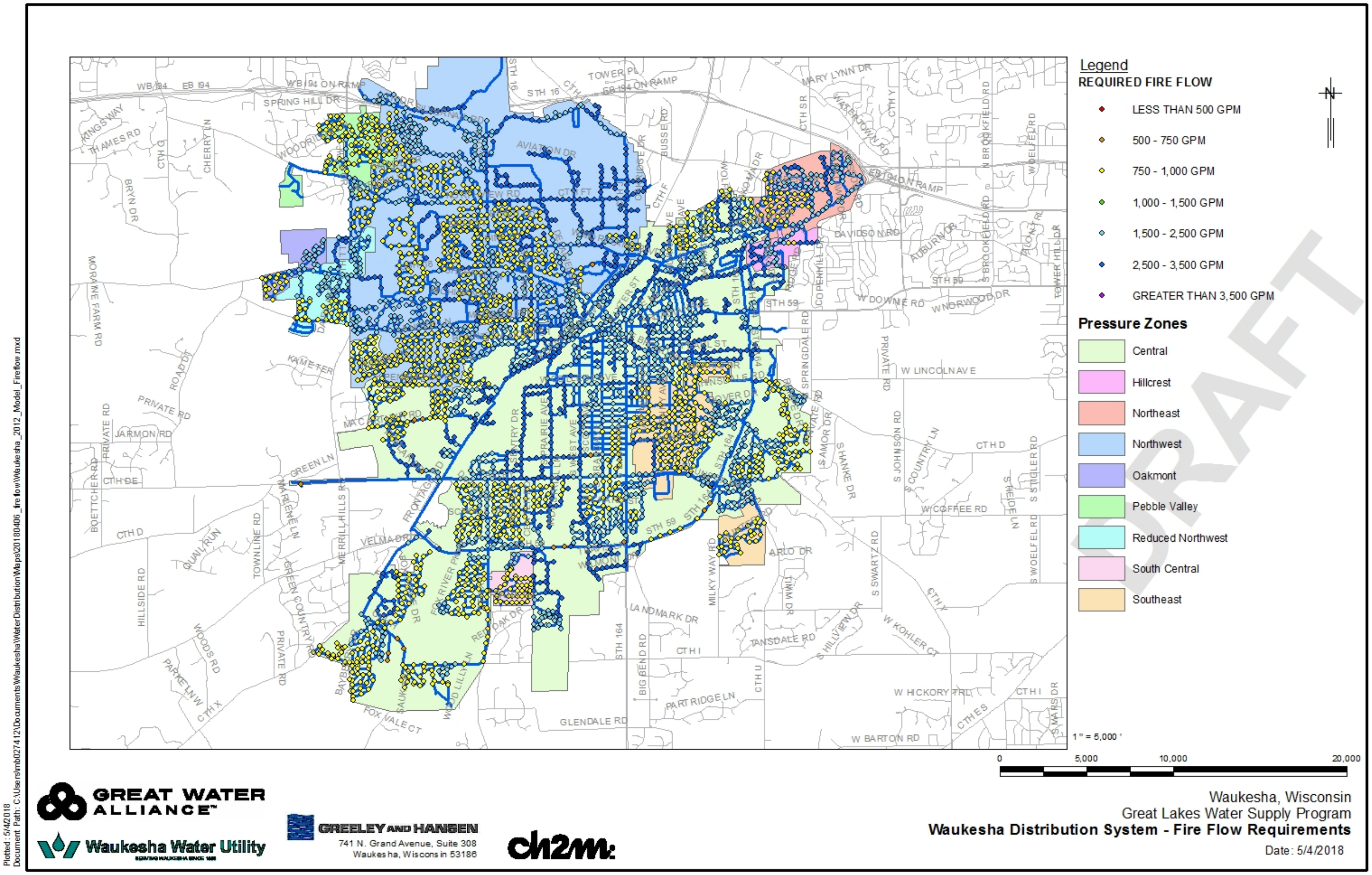


Figure 3-5. Fire Flow Requirements

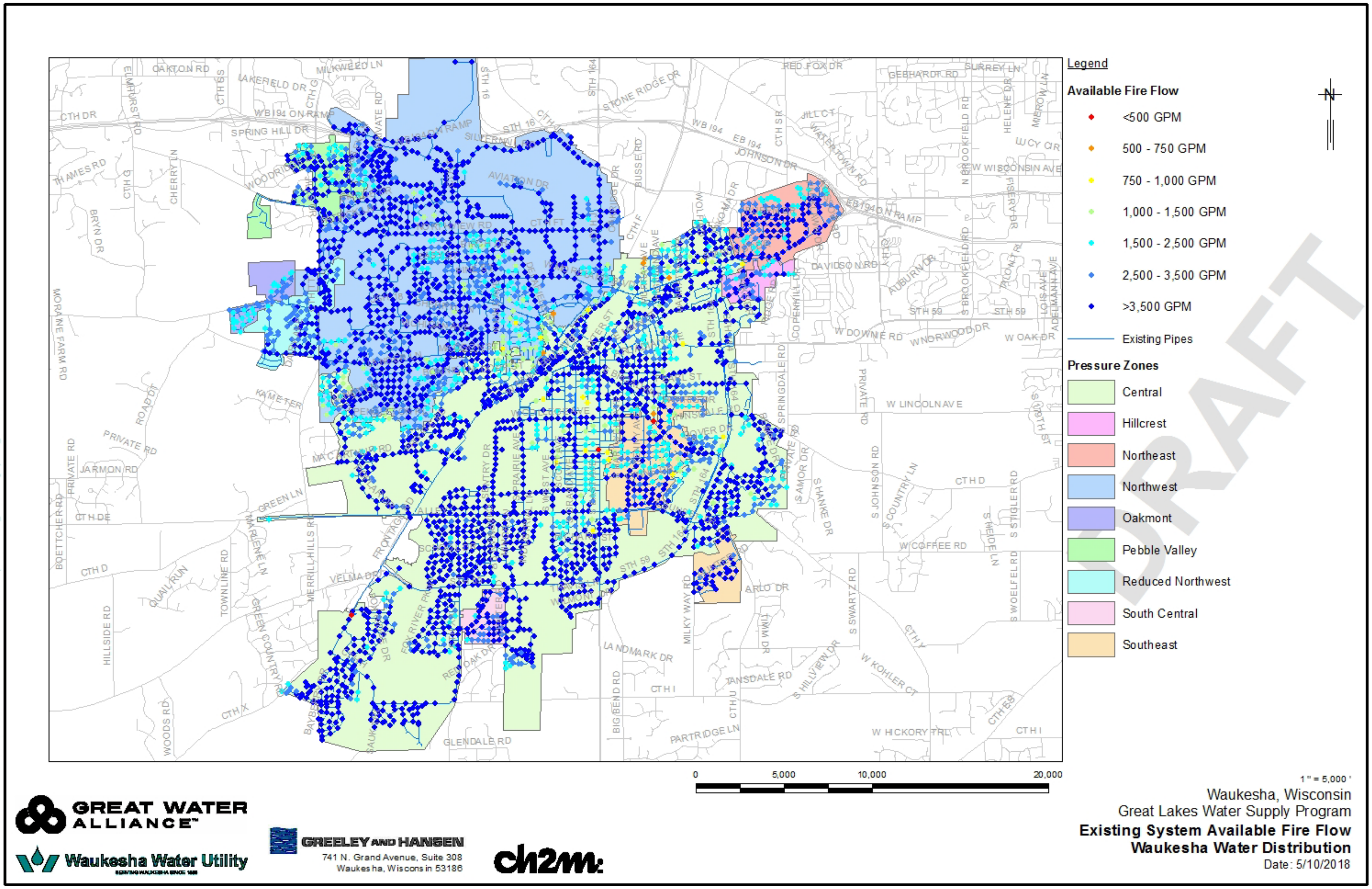


Figure 3-6. Available Fire Flow

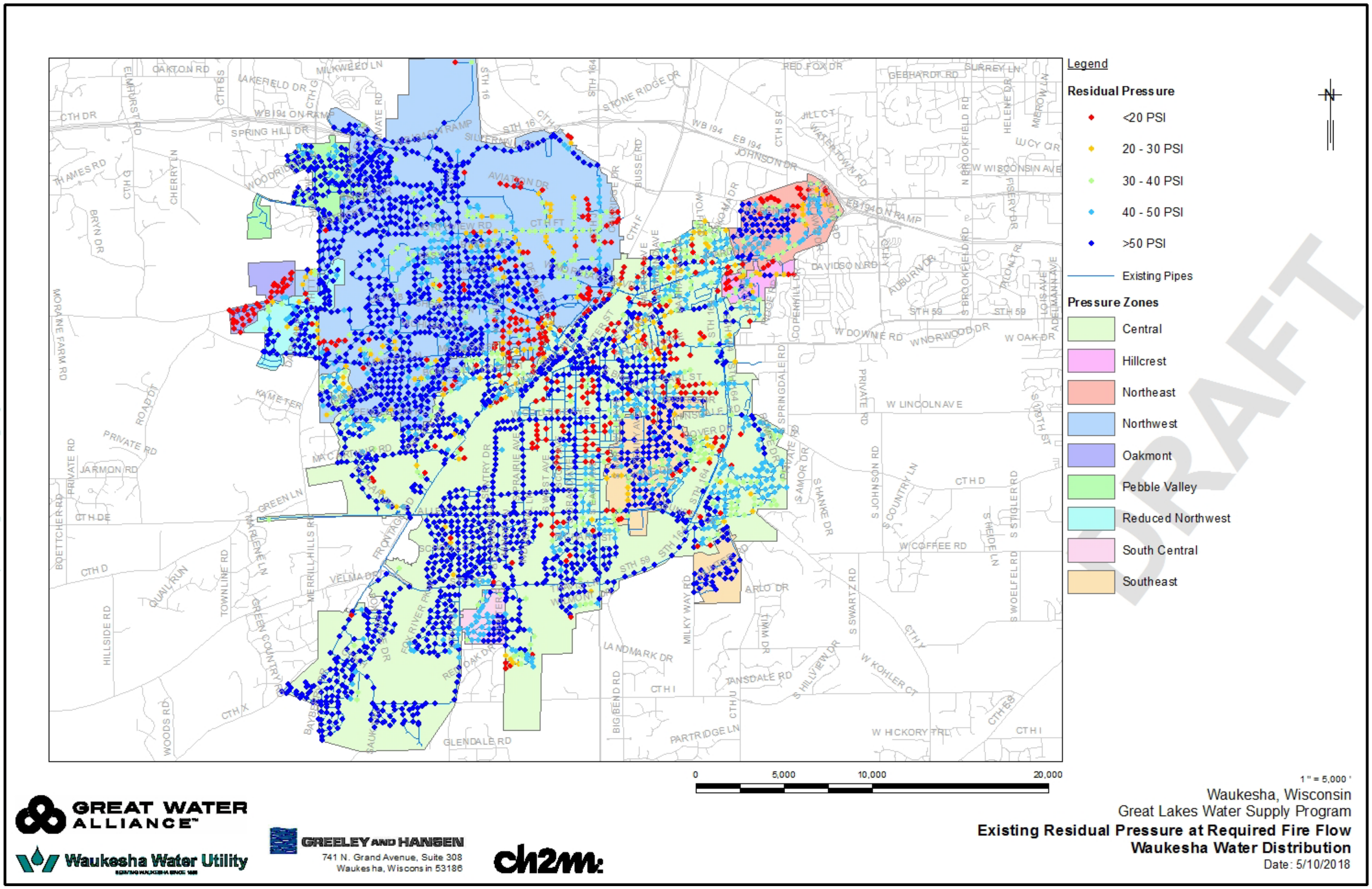


Figure 3-7. Residual Pressure during Fire Flow

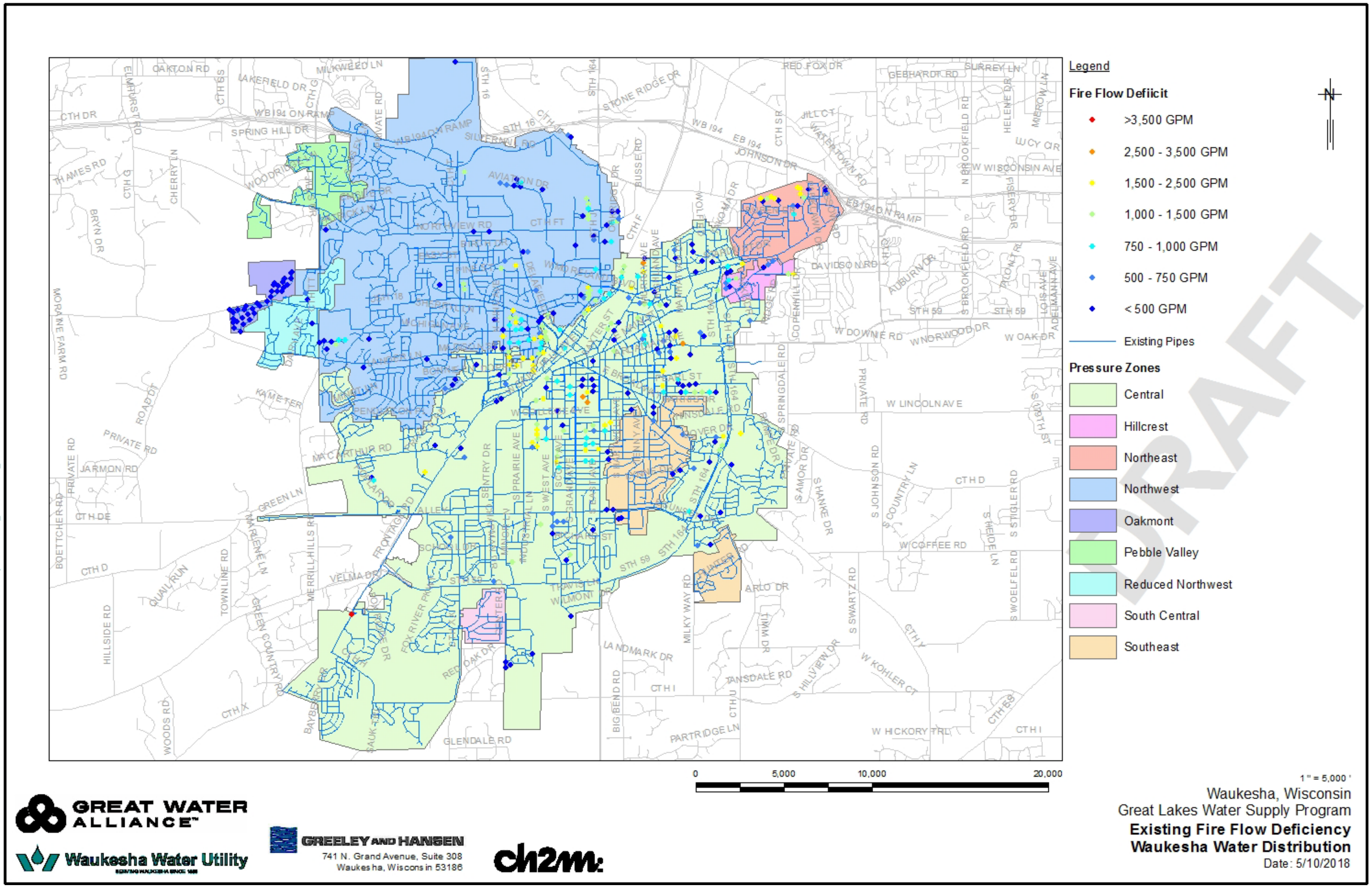


Figure 3-8. Fire Flow Deficit

3.3 Existing System Water Age

Water age is often used as a predictor of general water quality throughout a distribution system. Water age is calculated by the hydraulic model through an assessment of how water flows from water sources, through pumping and storage facilities, and through distribution system piping to customers. Allocation and simulation of water demand is critical to predicting water age since the water demand is the driver for moving water throughout the distribution system and causing the operational response of pump and tank operation at facilities in the distribution system.

The water age in the WWU system was evaluated under ADD conditions, and the results of water age are shown spatially in Figure 3-9. Note that water age is not shown at dead ends in Figure 3-9. Water age is not static within the distribution system, and in areas where there are long pipes to water storage facilities, water age can see dramatic variations due to the operation of the water storage reservoirs or towers. This is because there is a column of water that is moved “back and forth” to the water storage reservoir or tower that is not consumed by adjacent demand. This condition is especially prevalent around the Davis Tower. Areas in the pressure zone served by the Davis tower receive a supply of lower water age water when the Stardust Booster Pump Station is in operation to fill the tower; once the Stardust Booster Pump Station turns off and supply is provided by the Davis Tower, the water age increases due to not only the water age within the Davis Tower but also the water age in the piping to the Davis Tower.

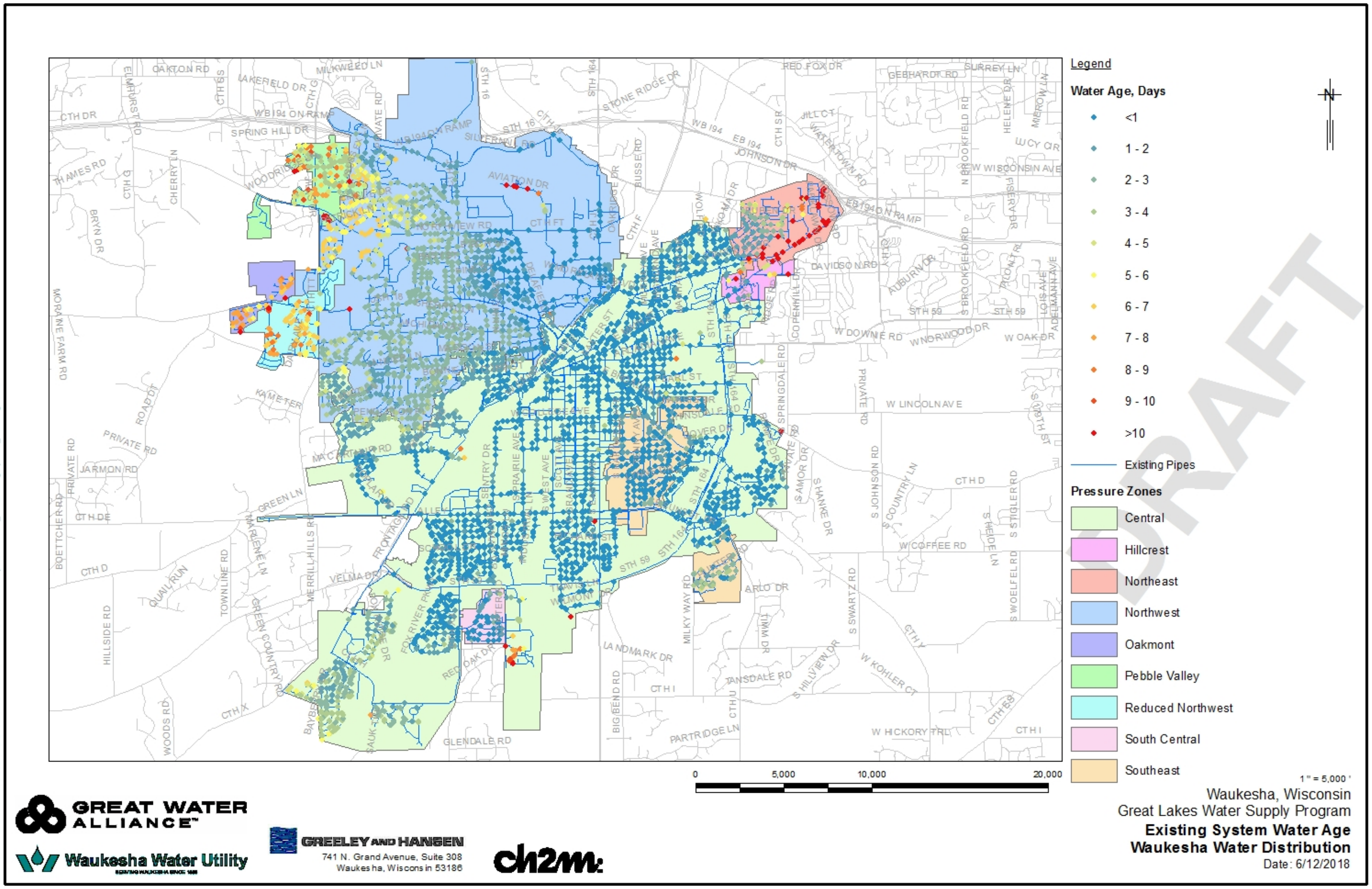


Figure 3-9. Existing System Water Age

SECTION 4 Connection Evaluation Approach

Four connection alternatives were identified by the team, and these locations are shown in Figure 4-1 through Figure 4-4. For each of these locations, two modes of providing back pressure and control of the Booster Pump Station (BPS) were considered and included using the Hunter Tower as a control feature for back pressure or using a control station with a pressure sustaining function to provide back pressure. The back pressure is required due to the elevation range along the transmission path from the new BPS to the WWU system.

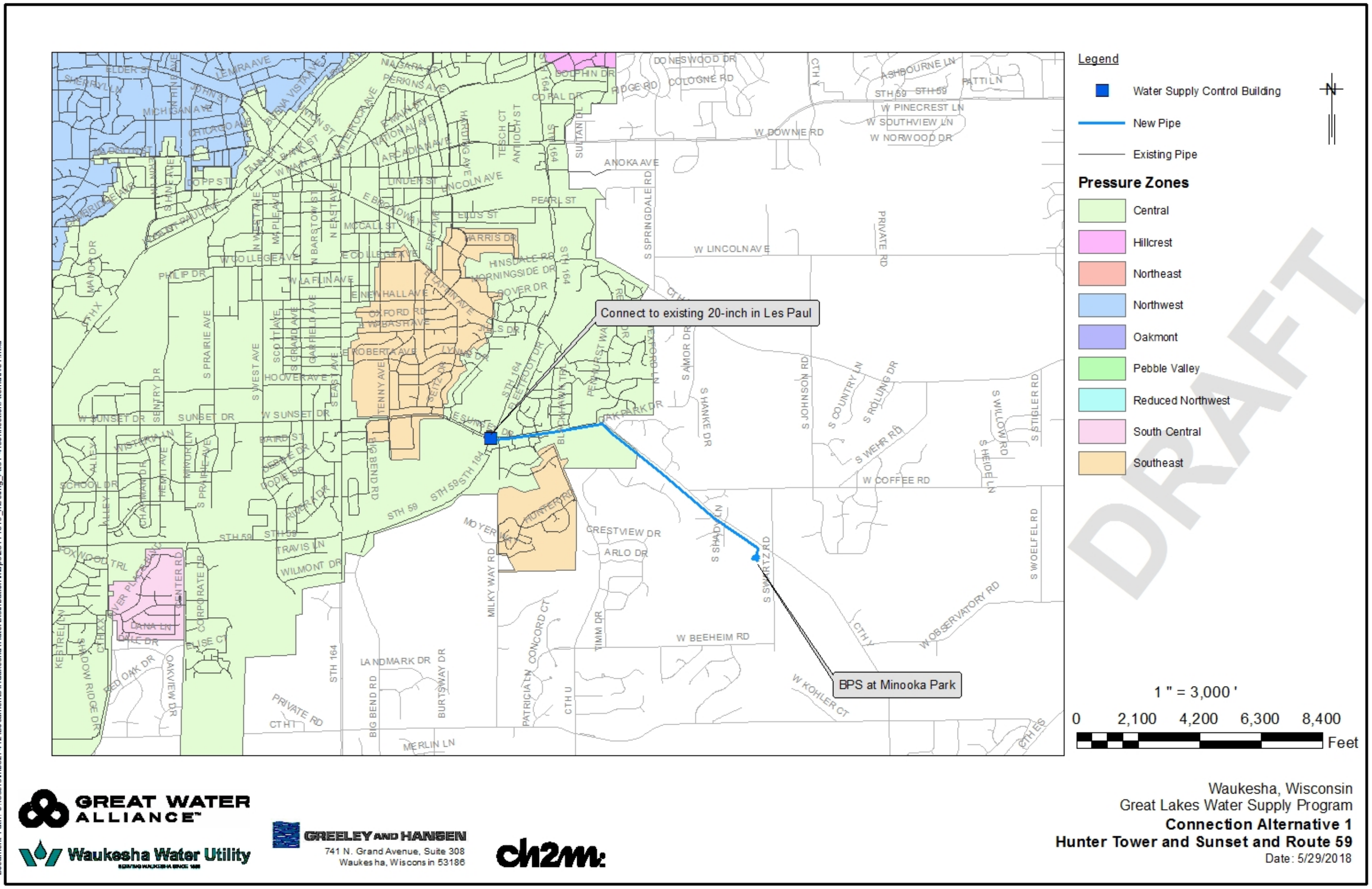


Figure 4-1. Connection Alternative 1

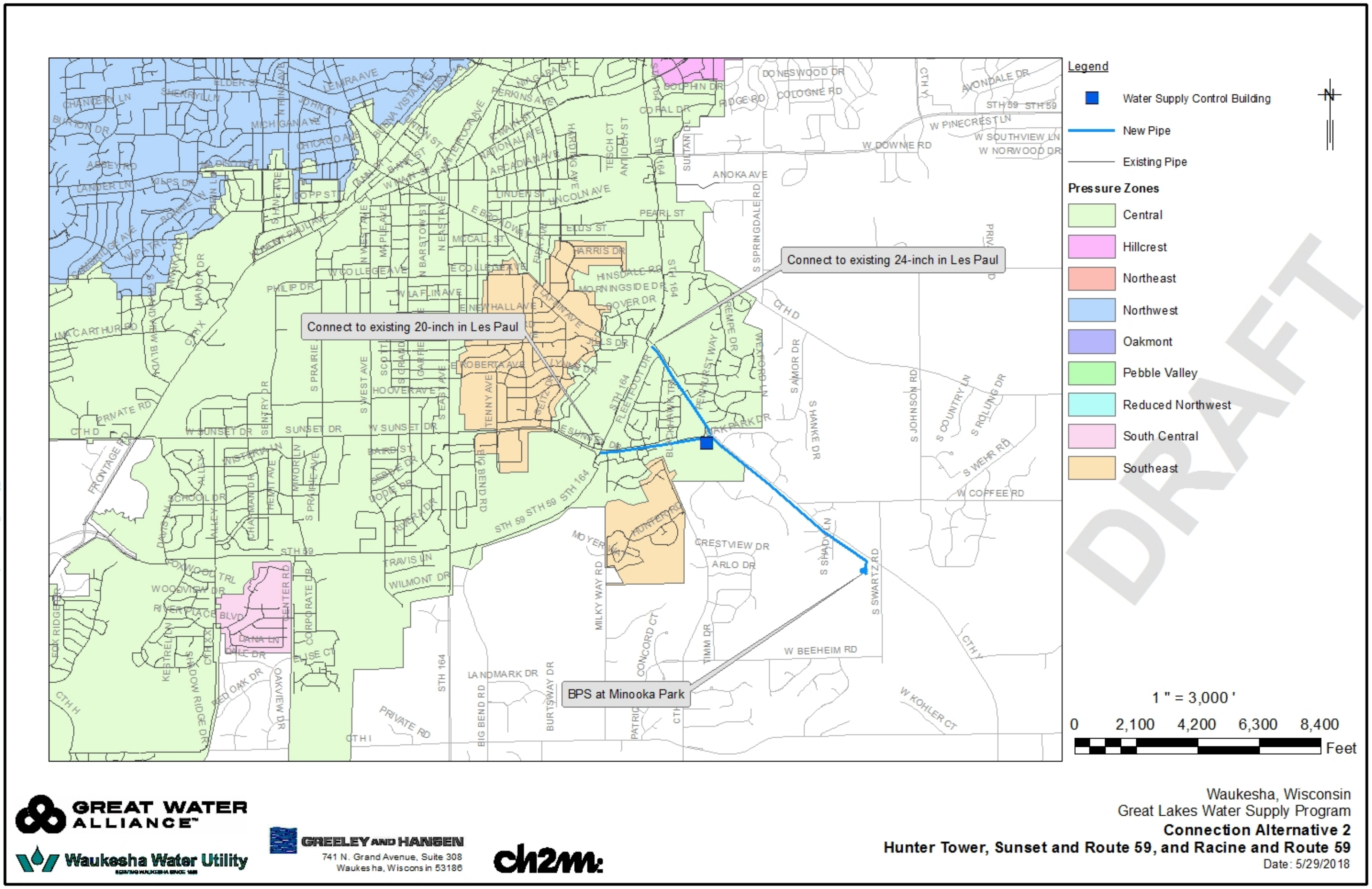


Figure 4-2. Connection Alternative 2

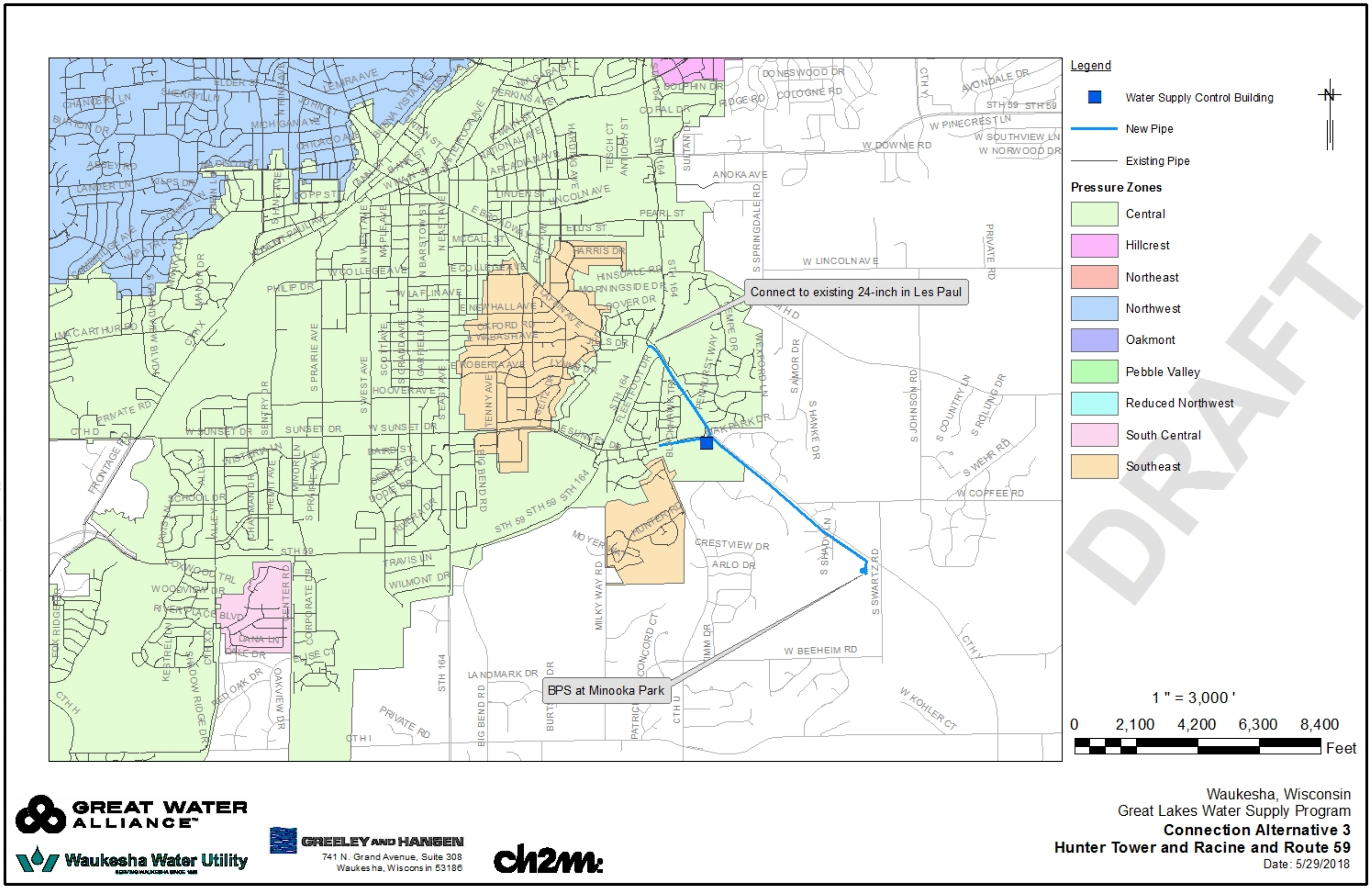


Figure 4-3. Connection Alternative 3

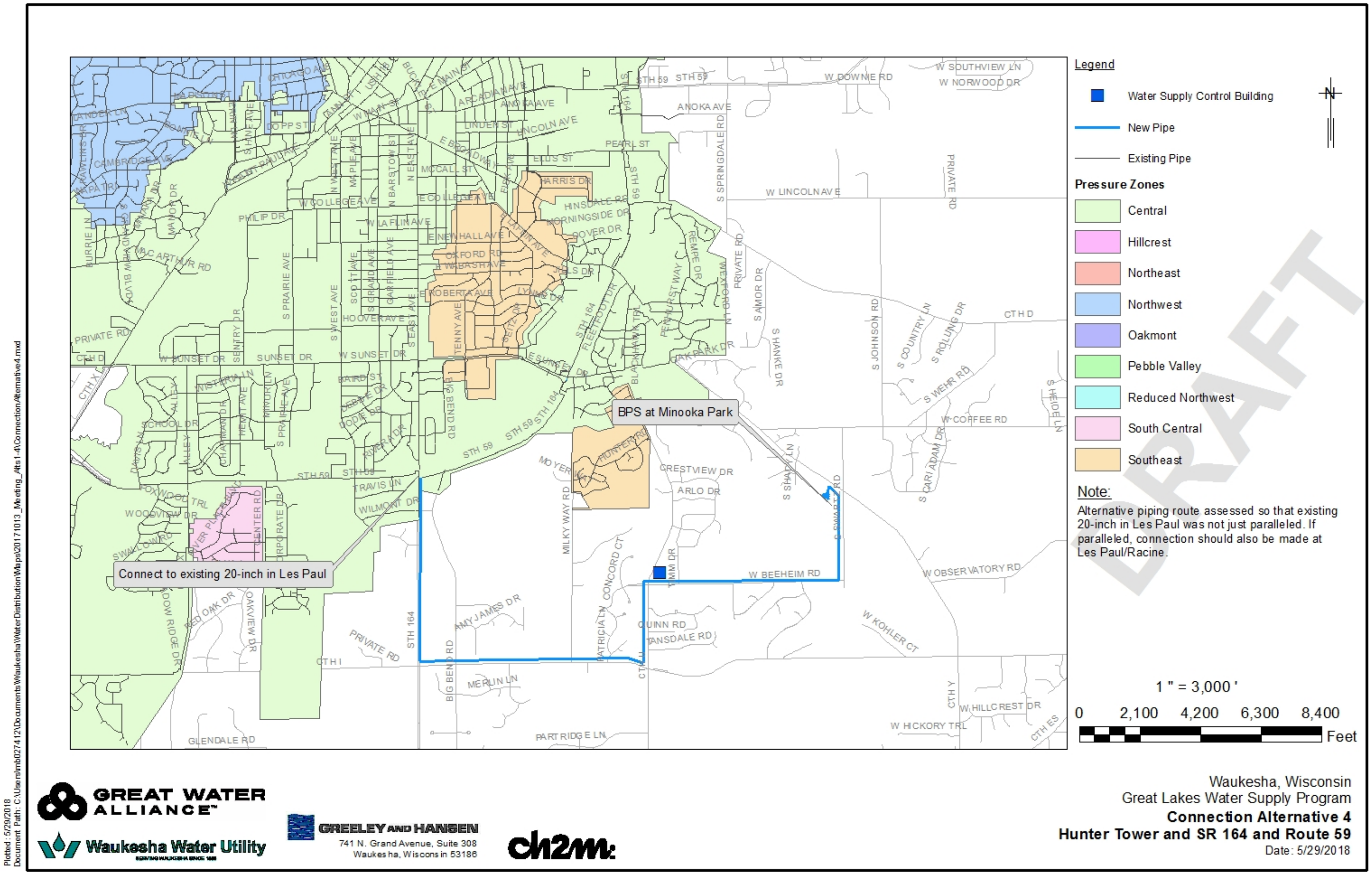


Figure 4-4. Connection Alternative 4

4.1 Connection Evaluation Strategy

The approach developed for evaluating the potential connection locations and operating strategies for the new supply followed a systematic, well defined process that engaged and solicited feedback from WWU staff throughout the evaluation so that numerous aspects of the WWU distribution system operation were considered. For example, facilities must be sized to meet MDD conditions but must also function well under ADD and low demand conditions. In addition, identifying the level of redundancy and facilities that are still needed to be maintained for providing a backup supply option must also be considered when identifying potential facilities that could be abandoned. The approach applied to evaluate each of the potential connection points consisted of the following steps:

- Perform storage analysis for future demand projections
- Define system operating strategy for meeting peak hour demand
- Develop operational scenarios for each connection point alternative, including new controls for existing ground storage tanks and pump stations as well as controls for the new ground storage tank and pump station for the new water supply so that supply is baselined
- Size facilities to meet MDD conditions and verify operation for ADD conditions
- Conduct scenarios as extended period simulations (EPS) to review system performance and operation
- Perform fire flow evaluation and review available fire flow

For the new booster pump station that delivers the new supply to the WWU system, the two operational scenarios for using the Hunter Tower or a Control Station used the strategies for MDD and ADD conditions summarized in Table 4-1.

Table 4-1. Control Strategies for the BPS for Hunter Tower Control and Control Station Control

Hunter Tower	Pressure Control Station
BPS is continually operated	BPS is continually operated
No pumping from Central to Southeast High Zone	Pumping (repumping) from Central to Southeast High Zone
BPS provides supply to Southeast High and Southeast Reduced	Central Zone supplies Southeast High and Southeast Reduced
Baseline pump plus pump that is ramped up or down based upon Hunter Tower Level	Baseline pump plus pump (s) that are ramped up or down based upon pressure setpoint

4.2 Evaluation Criteria

The evaluation criteria that were applied to confirm acceptable system performance and size new facilities included the following:

- Pressure: maintain pressure above 35 psi
- Velocity: maintain velocity less than 7 fps
- Tank Operation: allow for refill of ground storage tanks over a series of MDDs so that supply is available for meeting peak hour demands from ground storage tanks

4.3 Scenario Summary

Each connection alternative includes two modes of operation for the BPS. Each connection alternative then also considers two modes of operation in the WWU distribution system, with and without the Hillcrest Tank in service. While the Hillcrest Tank is a large, 5 MG tank, it is not at an elevation where the storage provides benefit to the WWU system. Only 0.63 MG of the 5 MG (12.6%) is considered for available fire flow storage, and the level Hillcrest Tank can drop to is limited due to resulting low pressure at higher elevation areas in the Central Zone. Table 4-2 provides a summary of the scenario evaluation matrix applied for evaluating each of the connection alternatives.

Table 4-2. Connection Alternative Scenario Summary and Approach

Demand Condition	Connection Alternative[1]			
	1	2	3	4
Existing ADD	Assess operations, review water age			
Existing MDD	*Phase identified improvements,* assess operations			
Future ADD	Assess operations, review water age			
Future MDD	*Identify improvements*, assess operations			

[1]Each alternative includes 8 sub-alternatives including the following: 2 improvement configurations (with and without the planned Main Street improvements not constructed), 2 operational conditions for the BPS supply and 2 operational conditions for operation with and without the Hillcrest Tank.

SECTION 5 Storage Evaluation

Storage in a distribution system has several purposes and uses.

- **Equalization storage** is used daily and is the volume of storage that is used during peak hour demands that supplements the water supply.
- **Operational storage** is the volume of storage that supports pump operation between on/off levels. The target volume for operational storage in the WWU system is 15 percent of total storage.
- **Emergency storage** is the reserve storage that is maintained to support periods of supply interruption.
- **Fire flow** storage is the reserve storage that is used during a fire flow event to supplement water supply during the fire flow event. The volume is equal to the fire flow rate (gpm) times the fire flow duration (hour).
- Emergency storage and fire flow storage are often “nested” and so may be counted together. Emergency storage can also be reduced if there is a redundant supply.

Using the demand projections shown in Table 2-1 and the methodology outlined in the 2012 WWU Master Plan, a storage evaluation was performed on the Central Zone and is summarized in Table 5-1. A portion of the existing ground storage tanks has historically been allocated to support the supply well operation. In the future, only the bottom six feet of the ground storage tanks were not included in the available storage volume. The bottom six feet were reserved to provide sufficient suction for the booster pump stations at each of the ground storage tanks. This change in available storage determination increases the available storage by 2,641,000 gal and depending upon the facilities that remain in service, this increase in available storage could offset the volume of storage maintained at the new supply facility near Waukesha. The storage evaluation presented in Table 5-1 shows that for existing conditions and in the future, the required storage for the Central Zone can be met without Hillcrest and without either the Sunset or East ground storage tank.

Table 5-1. Central Zone Storage Evaluation Summary

Storage Category	Central Zone Storage (gal)		Central Zone Storage Without Hillcrest (gal)	
	Existing	Future	Existing	Future
Required Storage				
Equalization Storage[1]	773,000		1,057,000	
Operational Storage[2]	248,000		298,000	
Emergency Storage[3]	630,000		630,000	
Pumped Emergency Storage for Upper Zones[4]	585,000	619,000	585,000	619,000
Total Required	2,236,000	2,604,000	2,236,000	2,604,000
Available Storage				
Hillcrest	630,000	630,000		
Saylesville	1,575,200	1,575,200	1,575,200	1,575,200
Sunset	1,208,800	1,208,800	1,208,800	1,208,800
East	1,153,000	1,153,000	1,153,000	1,153,000
Total Available[6]	4,567,000	4,567,000	3,937,000	3,937,000

[1]Based upon Peak Hour Demand calculated with a 1.7 PHD/MDD peaking factor for a duration of 5 hours

[2]15% of Total Storage Required

[3]Fire Flow emergency volume only, fire flow volume calculated for a fire flow of 3,500 gpm for 3 hours

[4]Volume is associated with upper zones that are limited on storage within the zones for emergency storage and depend upon storage in the Central Zone for supplementing emergency conditions.

[5]Total available storage from Hillcrest is 630,000 gal based upon elevation of storage. Bottom 6 feet of ground storage reservoirs is not counted in available storage for BPS operation. Volume of ground storage reservoirs is further limited if wells are in operation to allow for periodic well operation.

[6]Total available storage meets future storage requirements with either the Sunset or East facility out of service. If both are kept in service, excess storage in Central Zone may offset storage at the new Booster Pump Station.

SECTION 6 Improvement Option Performance

Distribution system improvements were developed for each of the connection point alternatives to alleviate deficiencies that were identified when performing the scenario evaluation without system improvements. Alternatives to the currently planned improvements along Main Street were also developed to compare the potential benefit for modifying currently planned improvements with the change in the location of the delivery of supply that was assumed as part of the WWU Master Plan.

Operational controls for facilities serving the Central Pressure Zone were developed for the BPS supply system and for the ground storage tank (GST) operation in the distribution system. The operational controls for the pump stations and towers serving the higher pressure zones remained similar to the operation of the existing system, except for operation of the Southeast BPS and Hunter Tower for the scenarios that use the Hunter Tower for supply backpressure. A summary of the modified operational controls for the GSTs is provided in the following sections, along with figures showing system-wide pressures and recommended improvements for each alternative. Fire flow results and water age are presented for the selected improvement configuration.

With the new supply configuration, low pressures observed in the WWU distribution system were primarily located at the areas of high elevation in the Central Zone, near the hospital and the Central-Northeast pressure zone boundary. The current configuration of the WWU distribution system with a distributed supply from wells and booster pump stations (as compared to the single supply point for the new supply configuration), and the supply to the high elevation areas from nearby well facilities create an area of higher HGL that does not result in the low pressures observed with the new water supply configuration. To mitigate these low-pressure areas, additional conveyance provides limited benefit at a high cost since the low pressure is driven by the operating level of the Hillcrest Tank. While options to reconfigure and move the boundary between the Central and Northeast pressure zones further to the south was not preferred since WWU wants to maintain two supply options (Central Zone and Northeast Zone) to the hospital, continuing the piping of the Northeast Zone along Madison Street between S Washington Avenue and La Salle Street and transferring service of customers in that section of piping from the Central Zone to the Northeast Zone and dedicate the existing 12-inch Central Zone pipe to suction for the Madison Booster in this area would provide higher pressures here. This parallel pipe configuration is already used along Madison Street, east of La Salle Street and west of S Washington Avenue.

6.1 Future MDD Scenarios with Hillcrest Tank in Service

The Future MDD was applied and evaluated for each of the four connection point alternatives with the varying control scenarios for the BPS and for the WWU distribution system to identify the suite of system improvements that are needed to meet future supply conditions. Each connection point alternative was evaluated with and without the planned Main Street improvement to determine if the planned Main Street improvement needed to be supplemented or extended and what additional improvements may be needed to support future system operation. Figure 6-1 through Figure 6-8 show the improvement requirements for each connection point and with and without the Main Street improvement in service. All alternatives were conducted with the Hillcrest Tank in service. Pressures for each of the scenarios were above the minimum pressure of 35 psi, and results are included in Appendix A.

For Connection Alternative 1, shown in Figure 6-1 and 6-2, the supply point is located at Sunset Drive and Les Paul Parkway. Conveyance is required to convey the supply further to the west in the WWU distribution system, and is shown to be a 24-inch pipe from the connection point west along Sunset Drive to Prairie Avenue. If the Main Street improvement is not constructed, additional conveyance is also recommended as a 16-inch from near the Hillcrest Tank at Arcadian Avenue and Les Paul, along Arcadian Avenue to East Avenue. This conveyance in Arcadian Avenue takes advantage of the newly constructed 24-inch pipeline in Les Paul to convey water to the Hillcrest Tank and then conveys water toward the higher elevation areas in the Central Zone. The planned 24-inch shown in Figure 6-2 along Main Street from Manhattan to Clinton Street provides similar conveyance through the Central Zone with the Hillcrest Tank in service. The primary difference in the conveyance option shown in Figure 6-1 and the planned improvement in Figure 6-2 is that the route along Arcadian Avenue intercepts the new supply along Les Paul at an earlier point to convey to the west.

Connection Alternative 2 includes a connection point at Sunset and Les Paul as well as at Racine and Les Paul as shown in Figure 6-3 and Figure 6-4. The additional conveyance needed for Connection Alternative 2 is the same as Connection Alternative 1 for the option of continuing the Main Street improvement (Figure 6-4) or identifying an alternate route (Figure 6-3). However, the supply piping required for Connection Alternative 2 is slightly longer than for Connection Alternative 1 with the dual connections to the system. Also like Connection Alternative 1, the planned pipe in Main Street can replace the 16-inch pipe shown in Arcadian.

Figure 6-5 shows the improvement options for Connection Alternative 3 which is a single connection to the WWU system at Racine and Les Paul. The improvements required for Connection Alternative 3 are similar to those shown for Connection Alternatives 1 and 2 since the proximity of the connections to the WWU system are similar and all make use of the conveyance in the new 24-inch in Les Paul. The pipe in Arcadian is increased to 24-inch since the single connection point in Connection Alternative 3 is further to the north as compared to Connection Alternative 1 and additional supply is delivered and conveyed in this northern portion of the system. The planned pipe in Main Street shown in Figure 6-6 provides similar conveyance capacity and system performance as compared to the pipe in Arcadian and can replace the pipe shown in Arcadian for Connection Alternative 3 as well.

Connection Alternative 4 is a connection further west in the WWU distribution system, near East Avenue and Les Paul. With a connection point further to the west, Figure 6-7 shows that less distribution system improvement piping is needed along Sunset that helped convey water to the west from the connection points in Connection Alternatives 1, 2, and 3. However, the supply piping for Connection Alternative 4 is quite a bit longer than the piping for Connection Alternatives 1, 2, and 3. The planned 24-inch pipe for the Main Street improvement can also replace the pipe shown in Arcadian for Connection Alternative 4, and the improvements for the Main Street option for Connection Alternative 4 is shown in Figure 6-8.

Each of the scenarios and pipe improvements described above kept the Hillcrest Tank in service and increased pressure in the southeast area of the Central Zone with the new supply connection in this vicinity. However, by operating the Central Zone with a single point of supply with the Hillcrest Tank in service, the HGL in the WWU system is governed by the level in the Hillcrest Tank. Based upon the comparison of the high elevation areas in the Central Zone with the Hillcrest Tank operating levels, the Hillcrest Tank is too low to provide sustained HGL for the high elevation areas and requires some zone modification for the higher elevation areas to maintain sufficient pressure.

In addition to the pressure evaluation for each of the scenarios, the fire flow analysis presented for the existing system was repeated for Connection Alternative 1, with the Main Street improvement. The results of the fire flow analysis was similar, even with the higher future demands, showing deficient fire flow in areas of small diameter piping, dead ends, and high elevation areas. Results of the fire flow analysis for the future demand conditions are included in Appendix A.

6.2 Future MDD Scenarios without Hillcrest Tank in Service

Since there is sufficient storage in the WWU system without the Hillcrest Tank in service, scenarios were performed for each of the connection points without the Hillcrest Tank in service. By removing the Hillcrest Tank from service, the pressure setting at the entry point of the new supply could be increased by approximately 15 psi – 20 psi so that sufficient pressure was maintained at the high elevation areas of the Central Zone and so that there was sufficient driving head to refill the GSTs throughout a maximum day of demand without impacting system pressure. This increased entry pressure alleviated the need for any system piping improvements in the WWU distribution system, including the planned 24-inch in

Main Street. The operating strategy of the GSTs and pump stations was also slightly modified for this configuration. Pressure results for each of the ultimate scenarios without the Hillcrest Tank in service are included in Appendix A.

With the increase in pressure at the entry point without the Hillcrest Tank in service, a comparison of the distribution of maximum pressure in the Central Zone under MDD conditions with and without the Hillcrest Tank was prepared and is presented in Figure 6-9. This distribution of pressure shows that the number of locations with pressure between 90 – 100 psi increased as well as the number of locations with pressure between 100 – 110 psi. In the existing system, these locations also operated close to the pressures shown without the Hillcrest Tank since they are near the discharge of Well 13 and the Saylesville booster pump station for local supply.

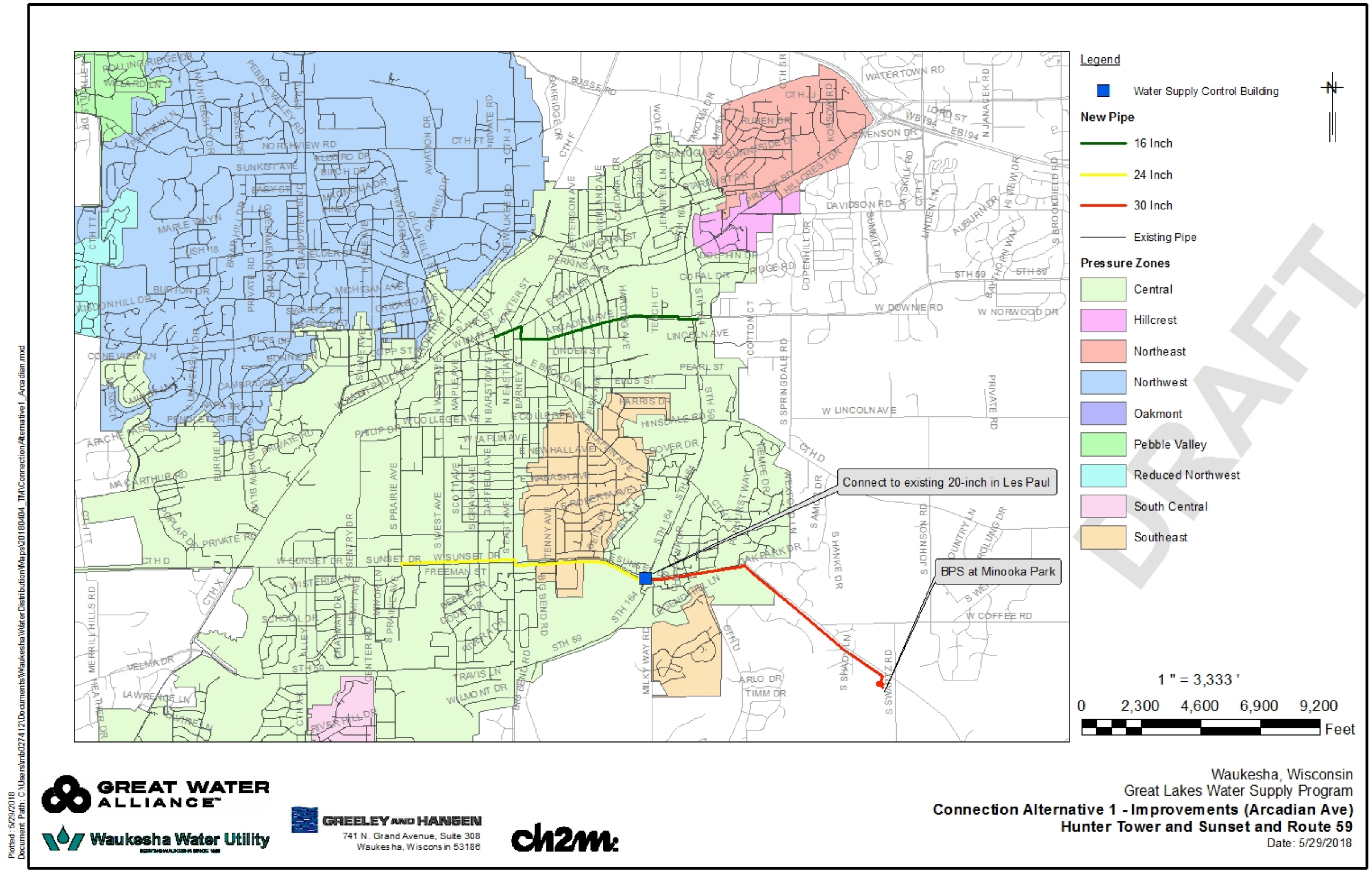


Figure 6-1. Recommended Improvements for Connection Alternative 1 without Main Street Improvement and with Hillcrest Reservoir in Service

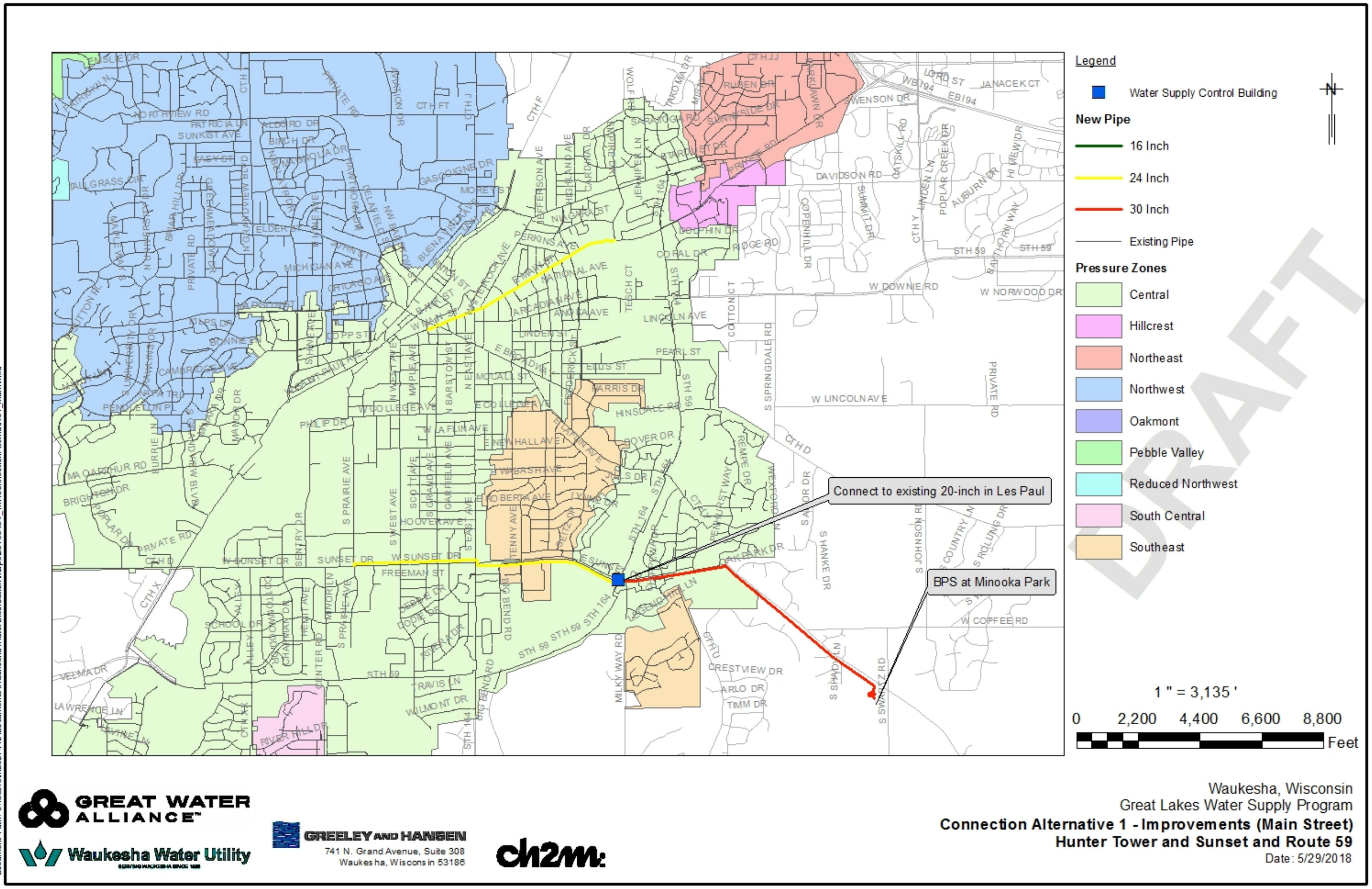


Figure 6-2. Recommended Improvements for connection Alternative 1 with Main Street Improvement and with Hillcrest Reservoir in Service

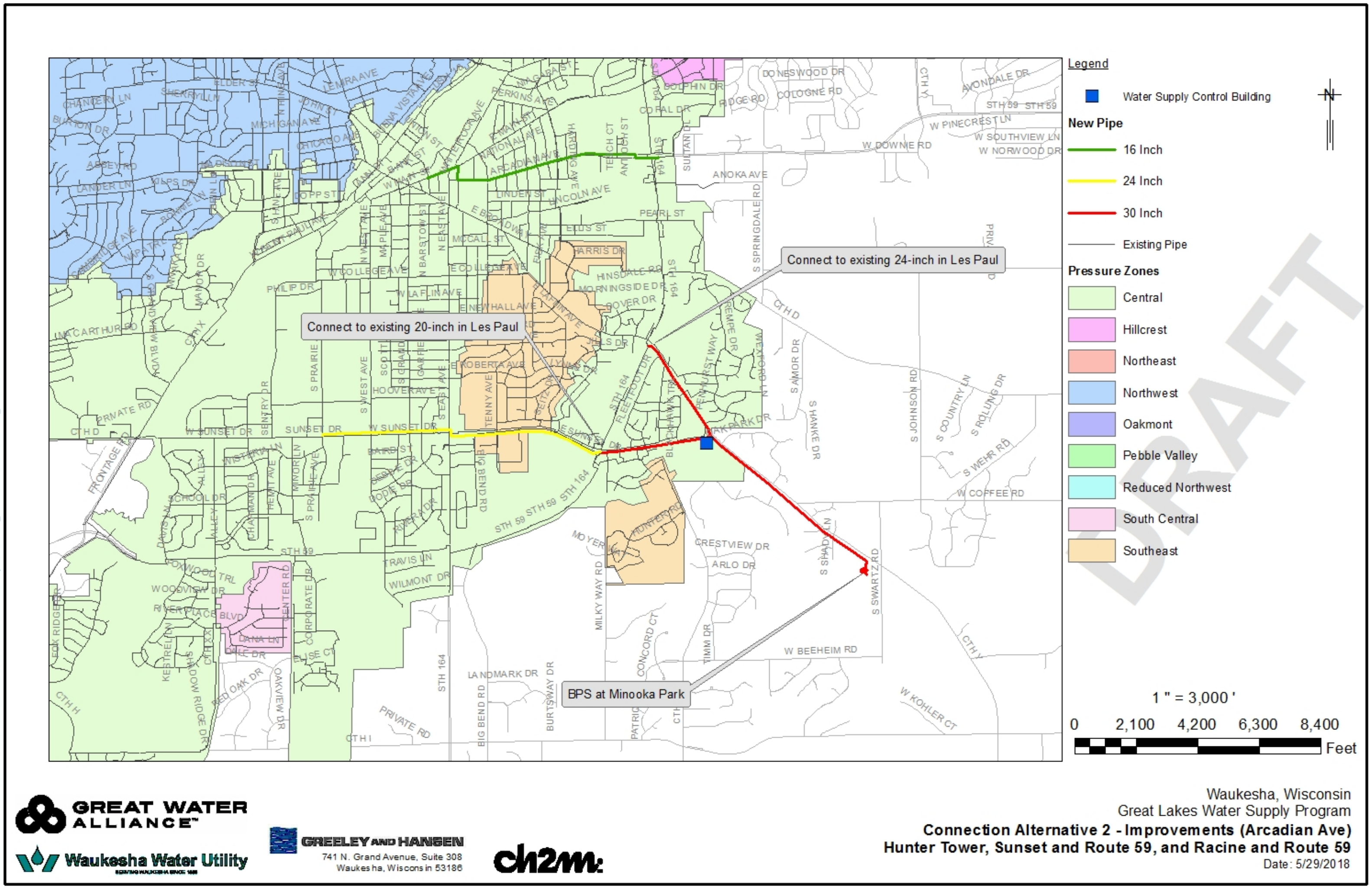


Figure 6-3. Recommended Improvements for Connection Alternative 2 without Main Street Improvement and with Hillcrest Reservoir in Service

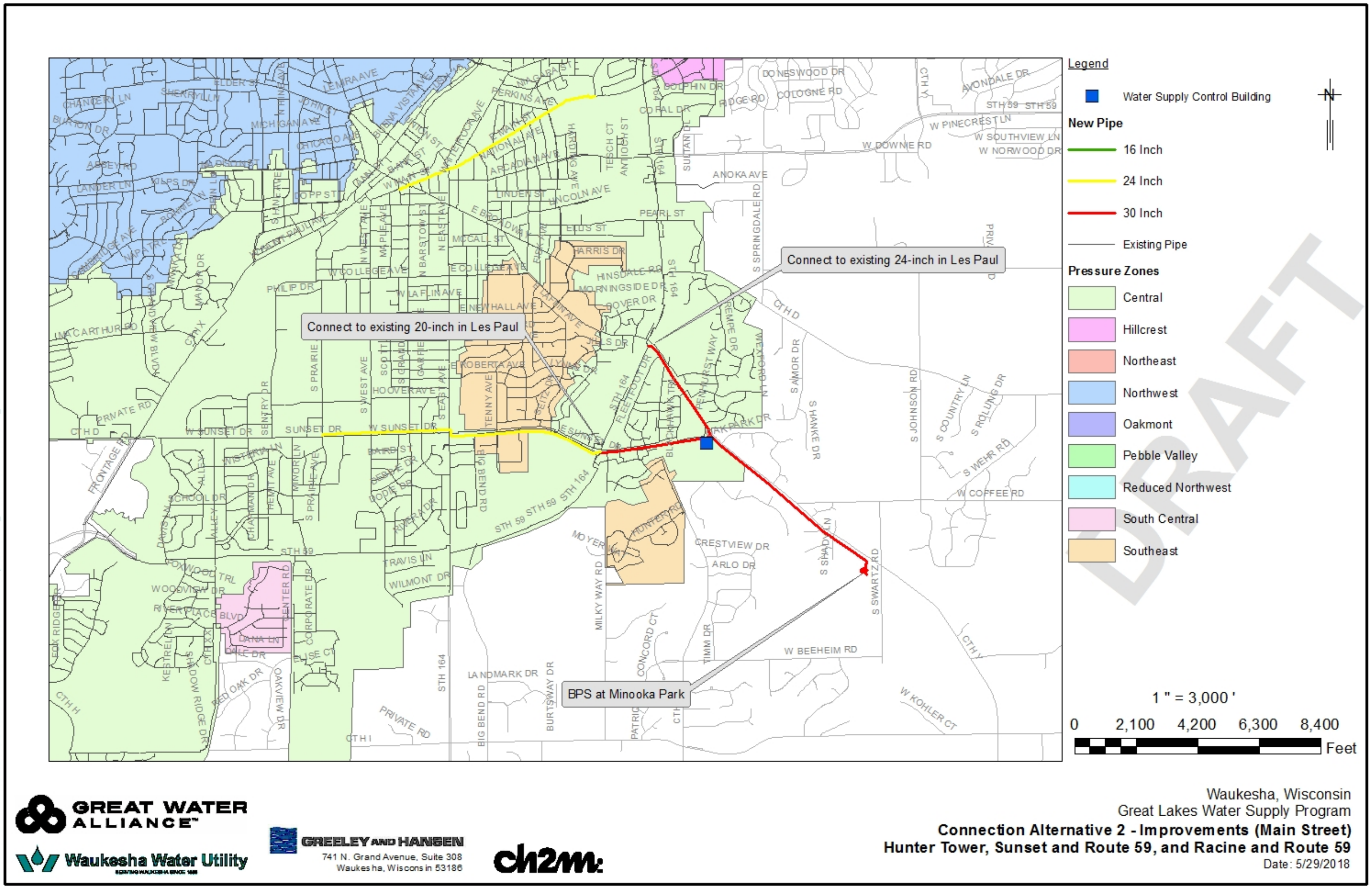


Figure 6-4. Recommended Improvements for Connection Alternative 2 with Main Street Improvement and with Hillcrest Reservoir in Service

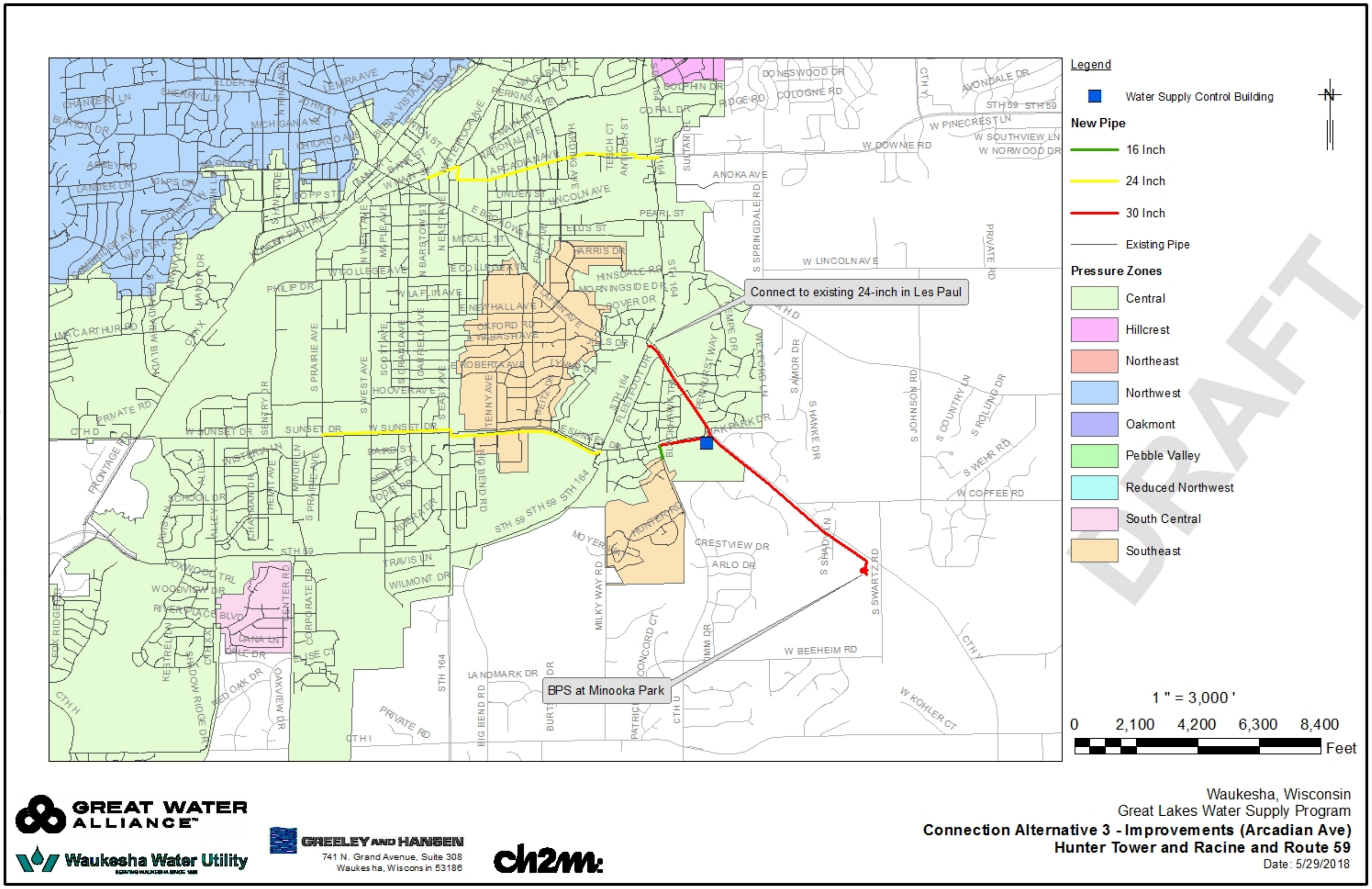


Figure 6-5. Recommended Improvements for Connection Alternative 3 without Main Street Improvement and with Hillcrest Reservoir in Service

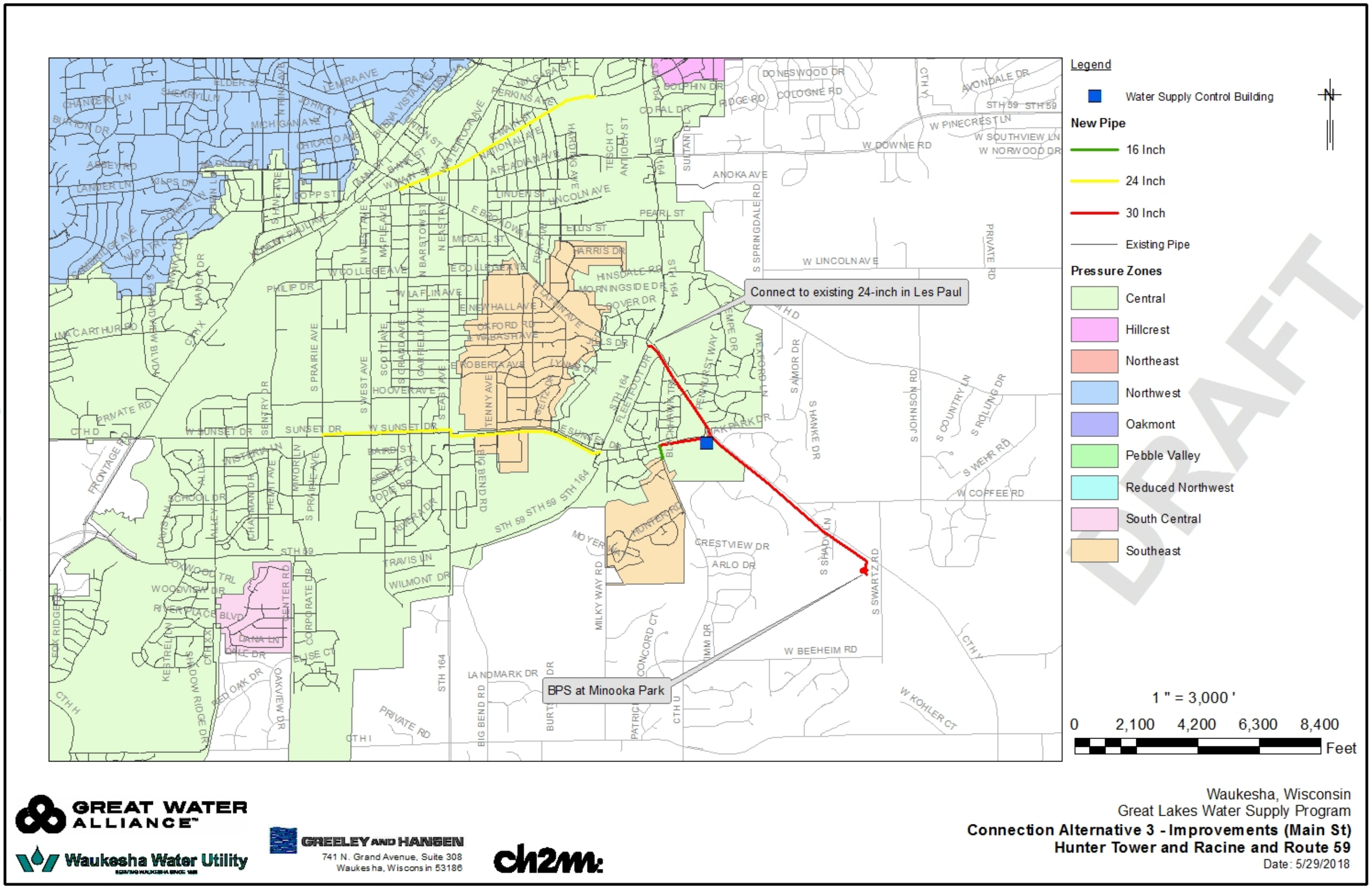


Figure 6-6. Recommended Improvements for Connection Alternative 3 with Main Street Improvement and with Hillcrest Reservoir in Service

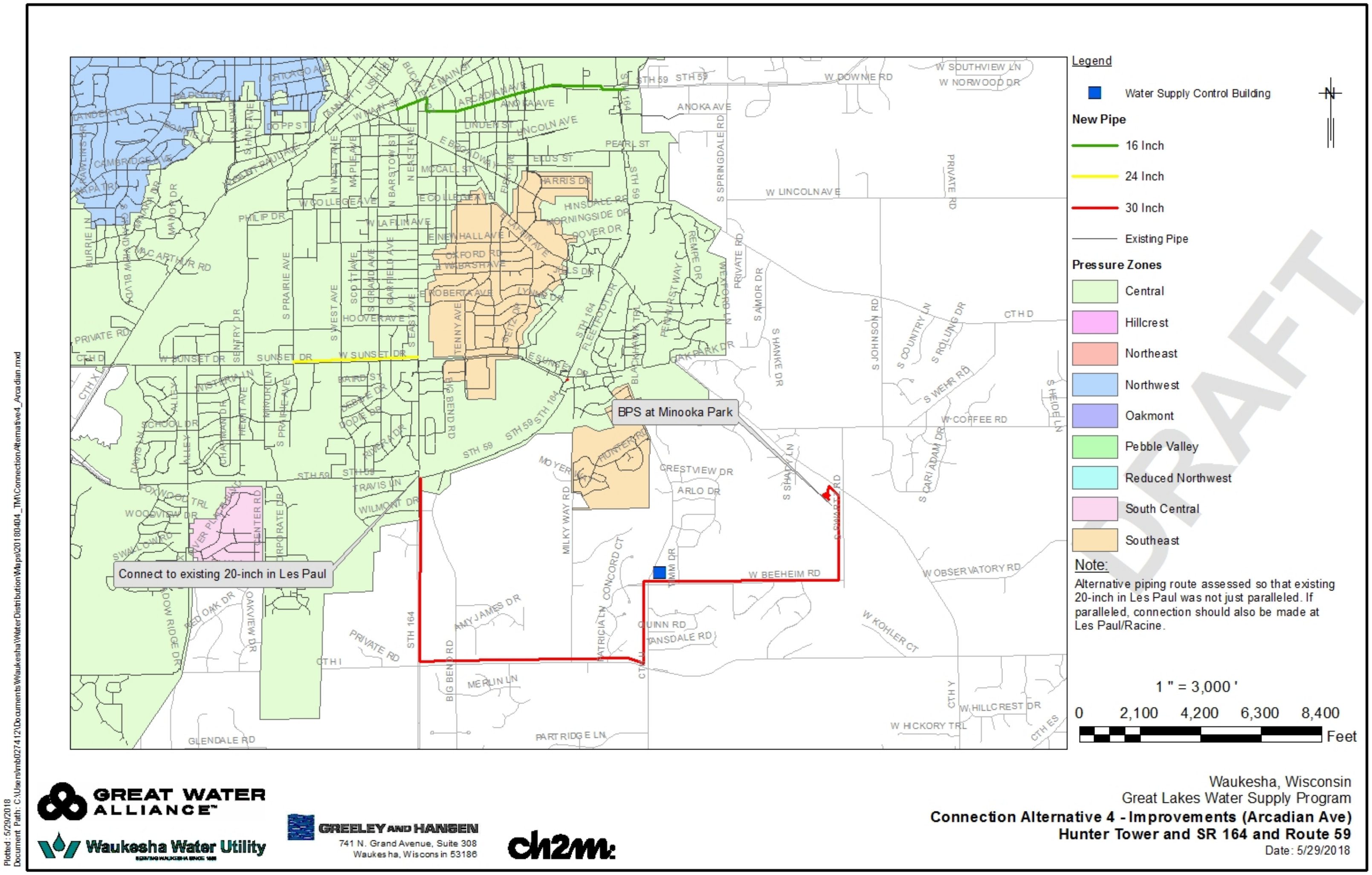


Figure 6-7. Recommended Improvements for Connection Alternative 4 without Main Street Improvement and with Hillcrest Reservoir in Service

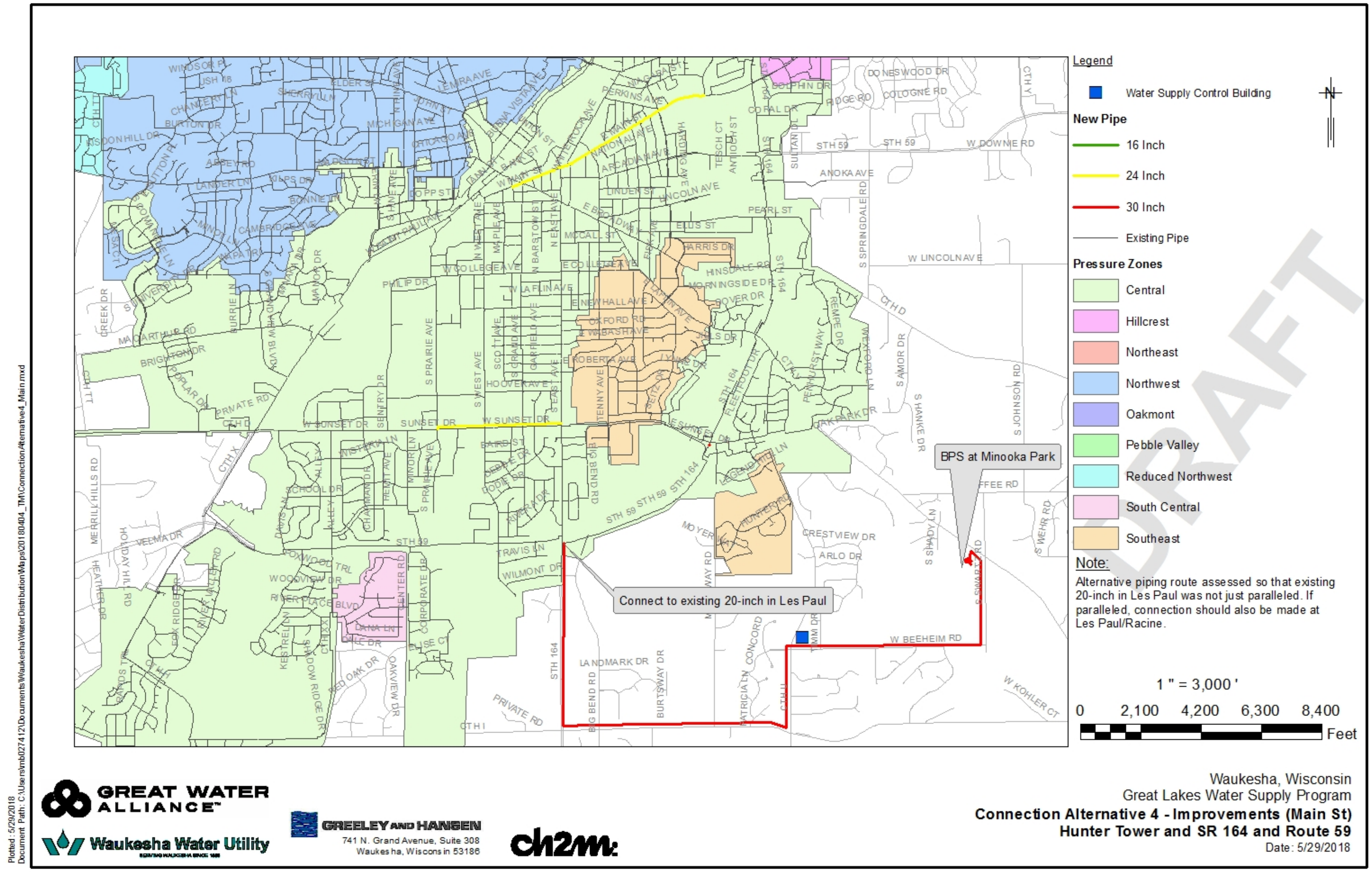


Figure 6-8. Recommended Improvements for Connection Alternative 4 with Main Street Improvement and with Hillcrest Reservoir in Service

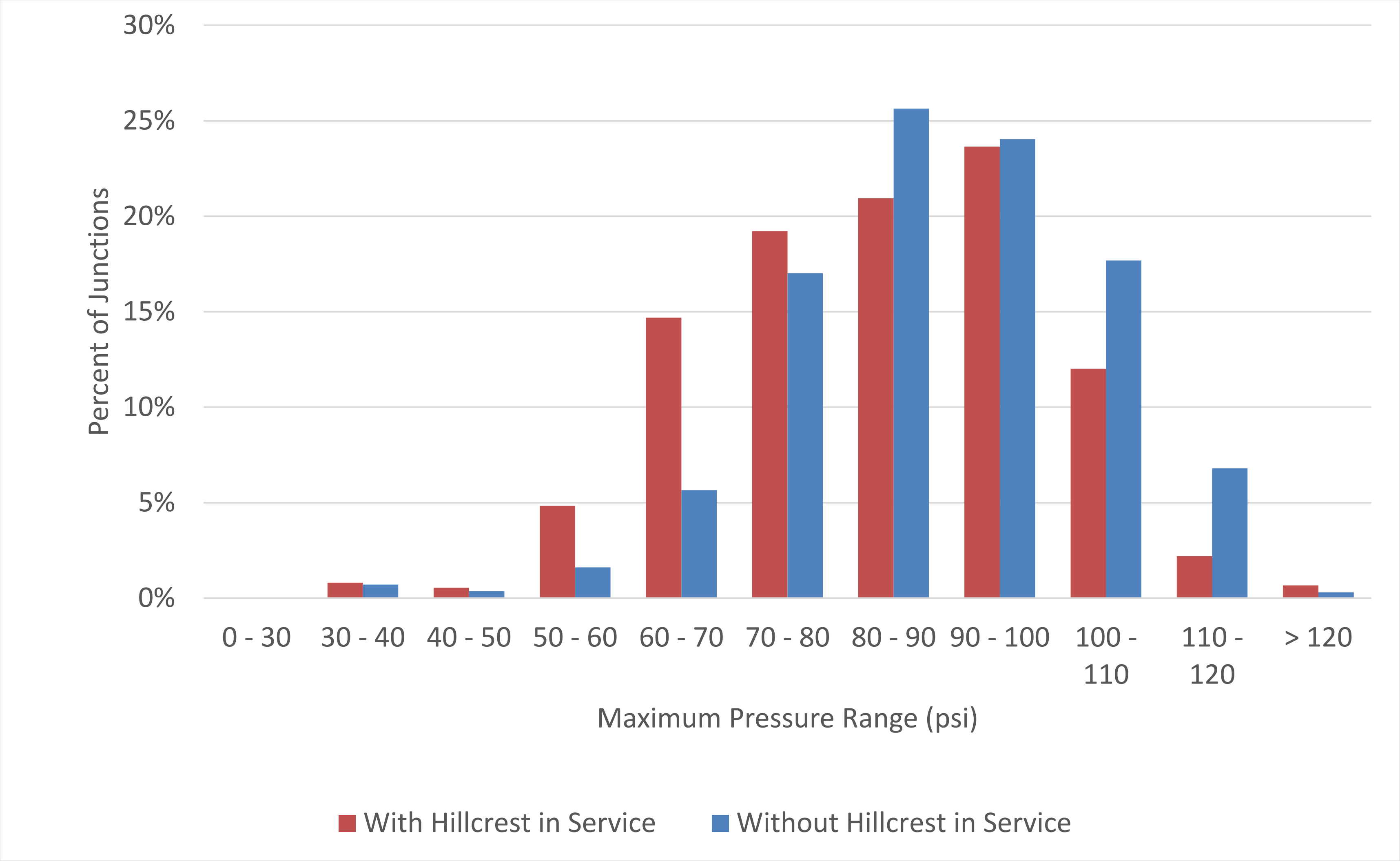


Figure 6-9. Pressure Distribution Comparison for Hillcrest Tank in vs. Out of Service

6.3 Future ADD Scenarios

Using the facilities identified for the each of the connection point alternatives, Future ADD scenarios were performed to assess the system operation with the new BPS facilities and the capability to continue to turn over the GSTs under ADD conditions. The ADD scenarios required minor modifications to the control scheme for the BPS by reducing the pressure at the control station. The GST operation could also be modified to use less of the available volume in the storage tanks to promote regular turnover of a smaller volume of stored water under lower demand conditions. Pressures for each of the connection alternatives were maintained above 35 psi for ADD conditions. Minimum pressure results for each of the future ADD scenarios are included in Appendix A.

A water age analysis was conducted for the future ADD scenario for Connection Alternative 1 with the Main Street improvement and for the conditions with and without the Hillcrest Tank in service. Even though a water age analysis was only performed for the selected Connection Alternative, the water age results for each of the Connection Alternatives will not show much variation since the supply is introduced to the system in similar locations, and the facilities that impact the water age are the Hillcrest Tank and the Crestwood Reservoir, Results of these water age analyses are included in Appendix A. As compared to the water age analysis for the existing system, water age for areas that are influenced by the Hillcrest Tank increase slightly with the new single point of supply in the future since not all of the new supply flows through the Hillcrest Tank as occurs with the Well 10 supply for the existing system. Since the Hillcrest Tank is a contributor to localized water age impacts within the system, there is some reduction in water age when Hillcrest Tank is not in service. Other facilities that influence water age with their operation and changes in operation from existing conditions to the future system configuration include the Crestwood Tank. There are areas within the Northwest Zone that periodically receive supply from the Crestwood Tank which has a higher water age than supply that is pumped by the inline Madison BPS.

6.4 Existing MDD Scenarios

Each of the connection point alternatives were also simulated for the existing MDD conditions and MDD plus fire flow conditions for Connection Alternative 1. The planned 24-inch in Main Street was included in the Existing MDD Scenarios. Under the existing conditions, no immediate distribution system improvements are needed to integrate the new supply except for the transition of services along Madison Street between S Washington Avenue and La Salle Street to the Northeast pressure zone. Fire flow deficiencies are shown in the same areas as for the existing system operation, including areas of small diameter pipe, dead ends, and high elevation. Since no other major improvements are needed immediately, this allows for the determination to be made about the future of the Hillcrest Tank and if it will be decommissioned to offset the additional system improvements and if the increased pressure (15 psi – 20 psi) at the connection point impacts other areas of the WWU system. Should the decision be made to keep the Hillcrest Tank in service, the additional system improvements needed for this operating condition can be phased. Minimum pressure results for each of the Existing MDD scenarios and the fire flow analyses are included in Appendix A.

6.5 Existing ADD Scenarios

The evaluation of the Existing ADD Scenarios was performed to confirm that the proposed system configuration could also be maintained under lower demand conditions and that the BPS and GST and pump station facilities that were sized for meeting future MDD conditions had sufficient operating range to efficiently meet lower existing ADD conditions. The water age was also evaluated for the existing ADD conditions for Connection Alternative 1. Like the Existing MDD runs, slight modifications were made to the control scheme for the BPS and GST/pump station facilities for the Existing ADD scenarios, and based upon the evaluation, the operating range of the proposed facilities met the system requirements across the range of demand conditions simulated. Minimum pressure results for each of the Existing ADD scenarios and the water age for Connection Alternative 1 are included in Appendix A. Pressures for each of the connection points was maintained above 35 psi, and the water age results were similar to those observed for the future ADD system evaluation, showing influence from the Crestwood Tank in the Northwest Zone and showing the influence of the Hillcrest Tank on water age within the Central and Northeast Zones.

6.6 Facility Control Summary

Key features and assumptions for the evaluation of each of the connection point alternatives across the range of demand conditions defined how the new BPS and Water Supply Control Building (WSCB) were operated to baseline supply to the WWU distribution system. Operation of the existing GST and pump stations within the WWU distribution system were also important since the GSTs and pump stations are operated to meet peak hour demand on a maximum day and must be refilled from the distribution system. As noted in the approach for the evaluation, simulations were performed for a series of six days so that it could be confirmed that the proposed operation of the system was sustainable and could be maintained over a period of several maximum day demands. A summary of the controls applied for each of the facilities within the Central Zone for each of the evaluation alternatives is provided in the following sections.

6.6.1 Booster Pump Station and Water Supply Station Control

The operational goal for the new water supply is to operate the water supply near to a baseline flow that allows for meeting peak demands from storage within the distribution system and then refilling distribution system storage during the low demand periods of the day. This approach to baseline the supply allows for smaller piping and facilities for the supply since the piping and facilities can be sized for providing closer to MDD rather than peak hour demand (PHD). A summary of the BPS Control for each alternative is summarized in Table 6-1 below. Similar control was provided for MDD and ADD conditions. As additional detail is defined for the selected pumps during design of the BPS, refinement of the controls for the full range of demand conditions is recommended. The control for the BPS was not varied from the control presented in Table 6-1 for the scenarios without the Hillcrest Tank in service.

Table 6-1. Summary of Booster Pump Station Control by Connection Alternative

Booster Pump Station Control		
Water Supply Control Building Only	Hunter Tower	
Two pumps run continuously. One pump provides baseline flow and second pump ramps up and down based upon supply needs	Run 1 pump continuously; Ramp second pump up and down second pump on based upon Hunter Level	Pump 2: Initial Speed = 83% Level > 34 ft, Speed = 80% Level < 25 ft, Speed = 83%, Level < 22 ft, Speed = 90% Level > 30 ft, Speed = 83%

The operation and pressure reducing valve (PRV) settings applied at the WSCS drive the system performance and turnover of the Hillcrest Tank in the WWU system. Each of the connection points required a different pressure setting for the WSCS due to the slight differences in the system hydraulics presented at the various connection locations, and these pressure settings are summarized in Table 6-2. In addition, the PRV settings for the ADD scenarios were lower since the headloss in the system was lower due to the lower flows. If the pressure settings were maintained higher under ADD scenarios when the Hillcrest Tank was in service, the Hillcrest Tank would fill and have limited turnover. The pressure settings for the WSCS did not vary between scenarios that included the Main Street improvement versus the Arcadian improvement. It is recommended that WWU consider remote/telemetry control for the pressure setting at the WSCS so that the setting could be changed based upon the season or also changed based upon the time of day to reduce the pressure during periods of lower, night-time demand.

Table 6-2. Summary of Water Supply Control Building PRV Settings by Connection Alternative

Alternative	Water Supply Control Building PRV Settings (psi)			
	With Hillcrest		Without Hillcrest	
	MDD	ADD	MDD	ADD
1	65.7	64	80	73
2[1]	61/65	60/63	75/79	65/73
3	63	61	79	72
4	78	76	93	87

[1]The first pressure listed is for the connection at Racine and Les Paul; the second pressure is the pressure at Sunset and Les Paul.

6.6.2 Ground Storage Tank and Pump Station Control

The operation of the WWU existing GSTs and associated pump stations is to provide supplemental water supply during peak hour demands each day. To supply the peak hour demand, the pump stations must turn on as the demand is increasing, and the GSTs must be refilled from the system during times of lower demands. The filling of the GSTs must also incorporate a pressure sustaining function so that the tank filling is performed at a rate that does not impact overall system pressures in the WWU system. The strategy for the WWU GST and pump station operation for each of the connection alternatives is summarized in Table 6-3 below. In addition to the Saylesville and Sunset operation shown below, the East GST could also be incorporated into this cycle if it is determined that the East GST remains in service in addition to the Saylesville and Sunset facilities.

Table 6-3. Summary of WWU Ground Storage Tank and Pump Station Control by Alternative

Alternative	Ground Storage Tank and Pump Station Control	
	Saylesville	Sunset
With Hillcrest in Service	Fill: Open Fill Valve at 6 PM, close when full or at 6 AM; Pressure Sustaining Setting = 62 psi Pump: Turn on pump at 7 AM, turn off pump at 1 PM	Fill: Open Fill Valve at 6 PM, close when full or at 6 AM; Pressure Sustaining Setting = 79 psi Pump: Turn on pump at 7 AM, turn off pump at 1 PM

Without Hillcrest in Service	Fill: Open Fill Valve at 6 PM, close when full or at 6 AM; Pressure Sustaining Setting = 71 psi Pump: Turn on pump at 7 AM, turn off pump at 1 PM	Fill: Open Fill Valve at 6 PM, close when full or at 6 AM; Pressure Sustaining Setting = 88 psi Pump: Turn on pump at 7 AM, turn off pump at 1 PM

The operation of the pumps used in the analysis at each of the GSTs was confirmed to be within the preferred operating range (POR) for each pump by evaluating the minimum and maximum points that the pumps operated at during each scenario. It is anticipated that no pump upgrades will be required as part of the system improvements with the new water supply but upgrades to incorporate controlled filling of the GSTs is required so that the filling of the GSTs occurs quickly enough to replenish the storage but is not too fast to adversely impact system pressures. The operating bands for each pump operated in each scenario are shown on the pump curves in Appendix B.

6.7 System Improvement Phasing

To assess when the identified system improvements for the alternatives that keep the Hillcrest Tank in service need to be implemented, an incremental increase in system demand was performed to identify what demand level triggered the need for the system improvements. Based upon this evaluation, the system improvements are needed when the MDD of the WWU system is sustained at 12 mgd. Based upon a linear growth of the MDD from 10.8 mgd to 13.6 mgd in 2050, WWU may reach a sustained demand of 12 mgd by 2032. A projected timeline of demand growth is shown in Figure 6-10, and based upon the growth rate of approximately 0.8 percent per year and the time to design and construct future improvements, improvement projects should be initiated when WWU reaches a demand of 11.5 mgd to allow for four to five years for the improvements to be designed and constructed. It is recommended that WWU continue to monitor ADD and MDD and regularly assess incremental changes and increases in ADD and MDD that trigger the need for the improvements sooner than the current projection of the rate of growth.

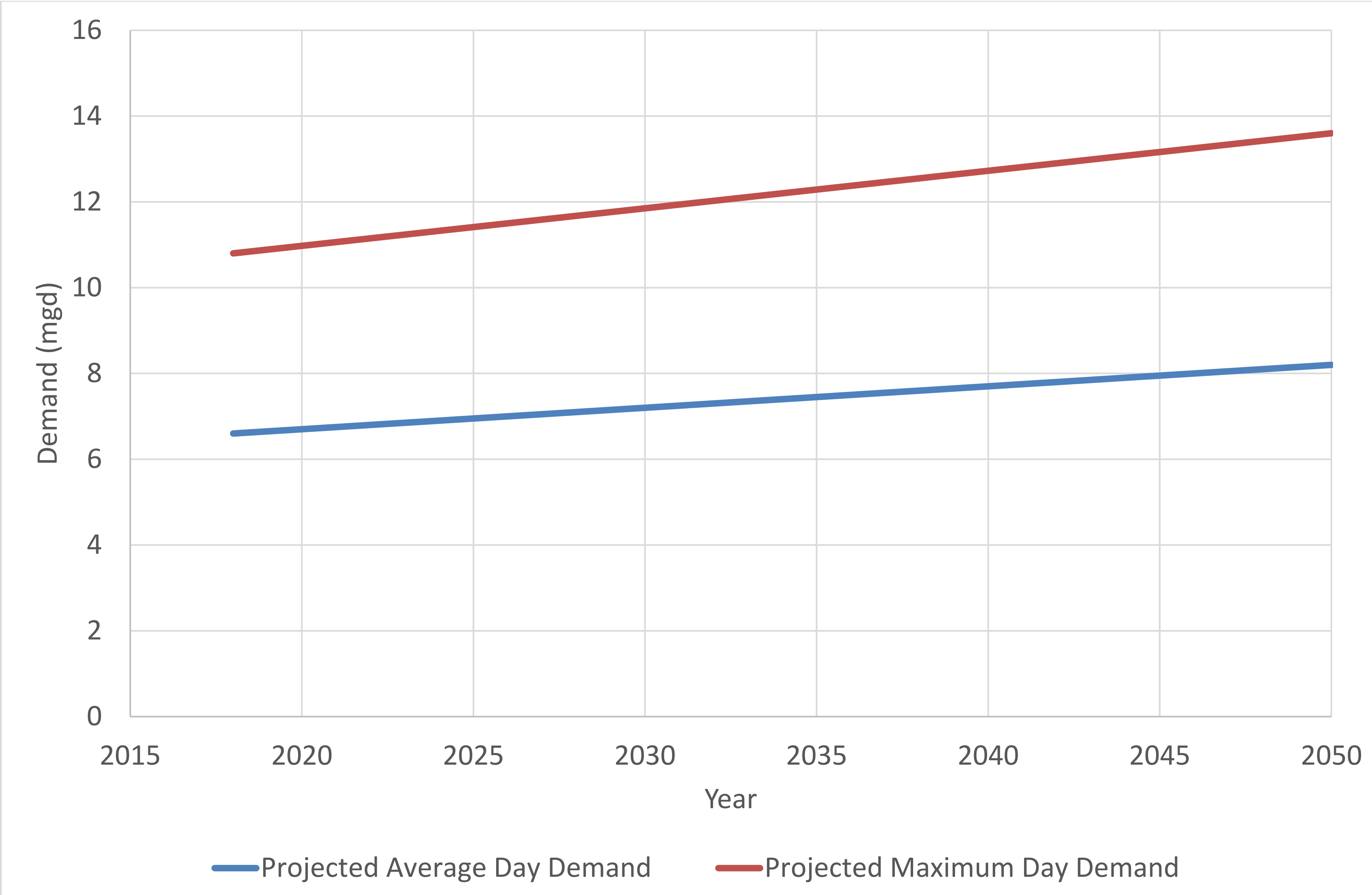


Figure 6-10. Projected Demand Growth for the City of Waukesha

SECTION 7 Summary and Recommendations

The improvements for each connection alternative presented above will meet the future system demand requirements and have the capability to operate efficiently during interim, lower demands. This section presents a summary of the evaluation of the alternatives and provides the recommendation of which alternative should be carried forward for implementation.

7.1 Connection Evaluation Summary and Cost Comparison

Distribution system improvements in the WWU distribution system were developed for each of the four connection alternatives developed. The improvements identified for each alternative conveyed water from the connection point further into the WWU distribution system. The improvement options were similar across the connection alternatives because the connection alternative points were close in proximity to each other and relied on similar existing facilities in the distribution system. Control schemes were also developed for each of the connection point alternatives for the new BPS facility and WSCS as well as the existing GSTs and pump stations in the WWU system. The control schemes are important for this analysis because the control schemes allow for baselining of flow from the new water supply and define how the existing WWU facilities are used to support the baselining of supply with operation during peak demand periods.

Several factors were identified to further evaluate and compare each alternative, and each alternative was assessed to determine if it provided the most benefit based upon each of the identified factors. Table 7-1 presents the comparison of the connection alternatives, including a comparison of operating the new BPS with control from the WSCS ("A" Options) or using the Hunter Tower for control and back pressure ("B" Options). Each alternative and configuration is rated on a score from 1 to 5 based upon the evaluation factor listed, and then a summary of the comparison of the alternatives for the evaluation factor is presented below the ratings. The sub-alternative configurations of removing the Hillcrest Tank from service and using the planned Main Street improvement in lieu of the Arcadian improvement were not specifically called out in evaluation presented in Table 7-1 since the performance of those variations on facilities is the same across all alternatives. The evaluation of these sub-alternatives is presented in the cost evaluation.

Table 7-1. Comparison of Connection Alternative Benefits

Evaluation Factor	Alternative Rating and Comparison							
	1A	1B	2A	2B	3A	3B	4A	4B
Variability in Supply Flow	4	2	4	2	4	2	4	2
	Performance is similar across connection alternatives and can be managed with the approach to BPS control; Using Hunter Tower requires direct response to tank level to achieve baseline flows and results in a lower rating.							
Energy	3	4	3	4	3	4	3	4
	Hunter Tower Control Connection provides benefit since pumping of Southeast High supply occurs “once” with Hunter Tank connection and control. All alternatives require repumping at GSTs.							
Fire Protection at BPS	3	4	3	4	3	4	3	4
	Hunter Tower Control Connection provides benefit by providing some backup for fire protection at BPS in the event of power loss.							
Supply Redundancy	3	3	4	4	3	3	3	3
	Connection 2 provides redundancy benefit with two points of connection							
Impact on Southeast High Zone Customers	4	2	4	2	4	2	4	2
	Hunter Tower Control Connection creates need for additional facilities and Tower is not fully dedicated to Southeast High Zone. Tower operation could be more variable when used as control point; Highline Booster Pump Station must be maintained as secondary supply for Southeast Zone							
Use of Existing Facilities	4	3	2	2	2	2	2	2
	Connection 1 provides a benefit with its connection near the Highline Booster Pump Station for the location of the WSCS.							
Sum of Ratings	**21**	**18**	**20**	**18**	**19**	**17**	**19**	**17**

Based upon the ratings for each of the categories, Connection Alternative 1, without the use of the Hunter Tower had the highest rating total. Connection Alternative 2 provides benefit by having two points of connection, and this is slightly outweighed by the capability to use existing WWU facilities for the WSCS for Connection Alternative 1. Even though the Hunter Tower connection provides some benefit in terms of reduced pumping for the Southeast High pressure zone, there were concerns identified with impacting and disrupting customers in this area with the use of the Hunter Tower as a control point.

To complement the non-cost evaluation of the alternatives presented above, a comparison of each of the connection alternatives based upon cost was performed to assess the relative benefits of the alternative for system operation as well as the connection alternative costs. Table 7-2 presents a summary of the costs for each connection alternative, including the options of using the Main Street improvement and removing the Hillcrest Tank from service. The connection specific costs identified in Table 7.2 include the piping costs for each connection and do not include the costs associated with the WSCS. The system piping improvements costs include the costs for the piping improvements associated with each option; the Main Street improvement costs include the costs for the piping along Main Street that is planned for construction in 2019 and has not yet been incurred by WWU. The total cost for each alternative is a sum of the connection specific costs, the costs for removing the Hillcrest Tank from service (where applicable), and the system piping improvements cost.

Table 7-2. Capital Cost Comparison for Connection Alternatives

		System Improvements Cost			
Connection Alternative	Connection Specific Cost[1]	Sunset Drive	Main Street[2,3], / Arcadian Street	Hillcrest Reservoir Demolition[4]	Total Cost[5]
With Hillcrest Reservoir (Sunset Drive and Main Street Improvements)					
1	$ 8.1 M	$ 5.5 M	$ 2.9 M	$ -	$ 16.5 M
2	$11.0 M	$ 5.5 M	$ 2.9 M	$ -	$ 19.4 M
3	$ 9.3 M	$ 5.5 M	$ 2.9 M	$ -	$ 17.7 M
4	$ 19.5 M	$ 3.6 M	$ 2.9 M	$ -	$ 26.0 M
With Hillcrest Reservoir (Sunset Drive and Arcadian Avenue Improvements)					
1	$ 8.1 M	$ 5.5 M	$ 4.5 M	$ -	$ 18.1 M
2	$ 11.0 M	$ 5.5 M	$ 4.5 M	$ -	$ 21.0 M
3	$ 9.3 M	$ 5.5 M	$ 5.3 M	$ -	$ 20.1 M
4	$ 19.5 M	$ 3.6 M	$ 4.5 M	$ -	$ 27.6 M
Without Hillcrest Reservoir (Hillcrest Demolition and Revised Main Street Improvements)					
1	$ 8.1 M	$ -	$ 1.7 M	$ 0.5 M	$ 10.3 M
2	$ 11.0 M	$ -	$ 1.7 M	$ 0.5 M	$ 13.2 M
3	$ 9.3 M	$ -	$ 1.7 M	$ 0.5 M	$ 11.5 M
4	$ 19.5 M	$ -	$ 1.7 M	$ 0.5 M	$ 21.7 M

[1]The costs for Connection Specific Costs include the cost to install 36" ducitle iron pipe along the length of each connection alternatives. Costs do not include any facilities associated with the connection to WWU.

[2]The costs for Main Street Improvements with the Hillcrest Reservoir remaining in service include 3,850 LF of 24" ductile iron pipe between Manhattan Drive and Lombardi Way. Costs do not include completed Main Street improvements or improvements between Barstow Street and Lombardi Way scheduled to be completed in 2018.

[3]The costs for Main Street Improvements without the Hillcrest Reservoir remaining in service include 224 LF of 6" ductile iron pipe, 1,144 LF of 8" ductile iron pipe, 1,130LF of 12" ductile iron pipe, and 1,030 LF of 24" ductile iron pipe along Main Street between Manhattan Drive and Lombardi Way.

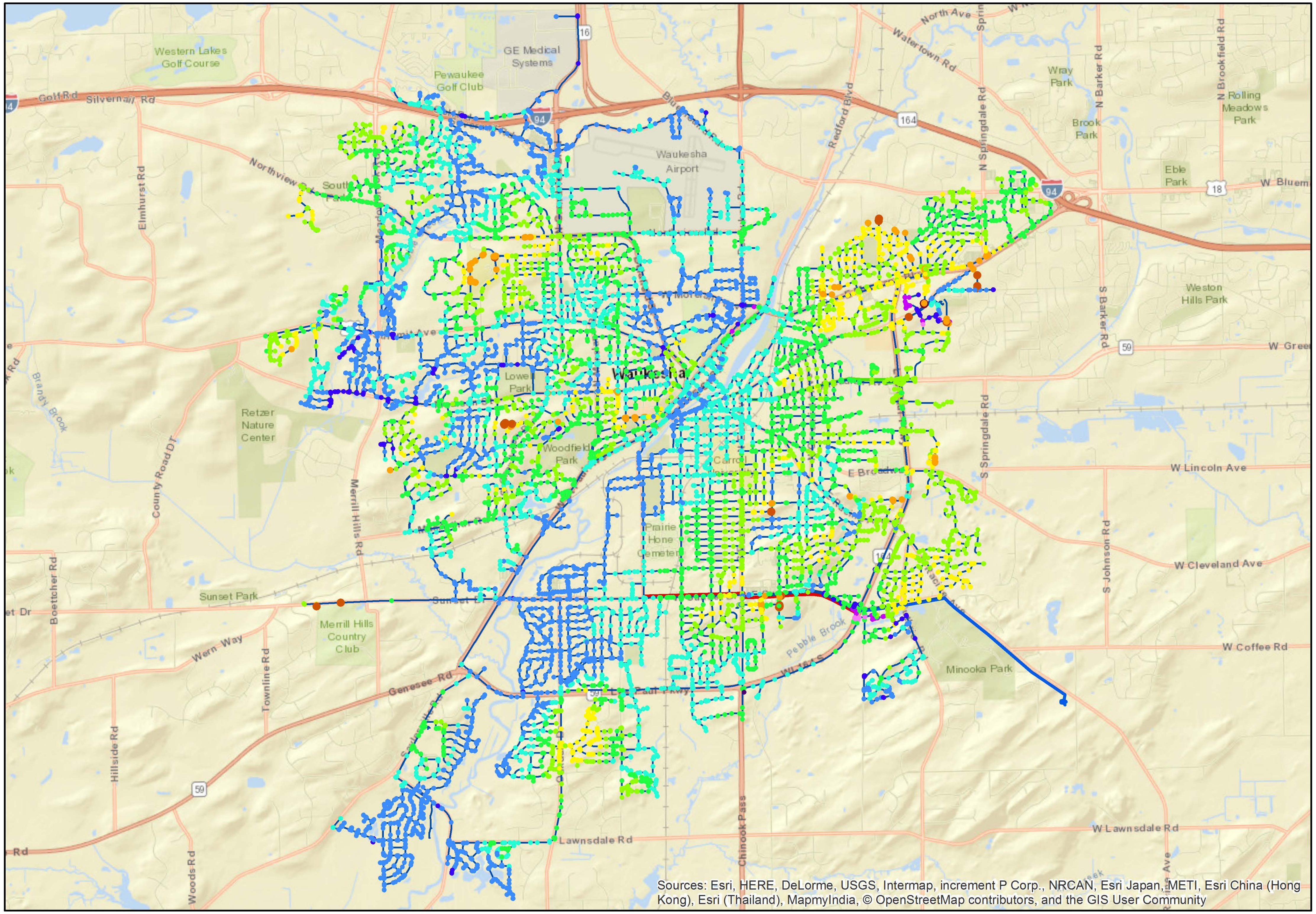
[4]The costs for demolition of Hillcrest Reservoir includes above grade reservoir structure demolition, backfill with demolished concrete and granular material, control building demolition, final site grading, plugging piping connections at reservoir, cut, plug and abandon in place 20" and 16" pipes at distribution connection at Main Street and 20" pipe connection at Shepherd Court.

[5]Costs are presented in June 2017 dollars and include capital cost with 3% bonds and insurance, 5% mobilization / demobilization, 25% contingency, and 15% contractor overhead and profit.

7.2 Recommendation

Based upon the alternative evaluation presented in Table 7-1 and the cost comparison presented in Table 7-2, Connection Alternative 1 is recommended for implementation, using the planned Main Street improvement. The use of the Hunter Tower as a control element should be further evaluated as the BPS pump sizes and individual pump capacity ranges are further refined to assess the benefits and drawbacks of the use of the Hunter Tower as the control element as compared to pumping directly to the WSCS from the BPS. It is also recommended that WWU further consider if the Hillcrest Tank can be removed from service to increase the supply pressure into the WWU system and minimize any additional system improvements with the additional driving head provided from the supply point. The cost of removing the Hillcrest Tank from service is considerably less than the cost of the additional improvements needed along Sunset. WWU will still have the capability to control the supply pressure into the system with the WSCS and can manage this supply pressure throughout the day with telemetry that is planned at the WSCS. Since the system improvements identified are not required until the sustained supply for MDD to the system reaches 12 mgd, WWU may consider keeping the Hillcrest Tank in service when the supply conversion is made and then pilot the operation without the Hillcrest Tank in order to make the decision of whether they are comfortable in removing the tank from service.

Appendix A – Connection Alternative Pressure Results



Legend

Minimum Pressure (psi)

- less than 20.00
- 20.00 ~ 35.00
- 35.00 ~ 40.00
- 40.00 ~ 50.00
- 50.00 ~ 60.00
- 60.00 ~ 70.00
- 70.00 ~ 80.00
- 80.00 ~ 90.00
- 90.00 ~ 100.00
- 100.00 ~ 110.00
- 110.00 ~ 120.00
- greater than 120
- Active_Mains
- New Pipe, 16"
- New Pipe, 24"
- New Pipe, 30"

N

DRAFT

1 " = 5,000 '

0 3,500 7,000 10,500 14,000 Feet

Plotted: 3/4/2018
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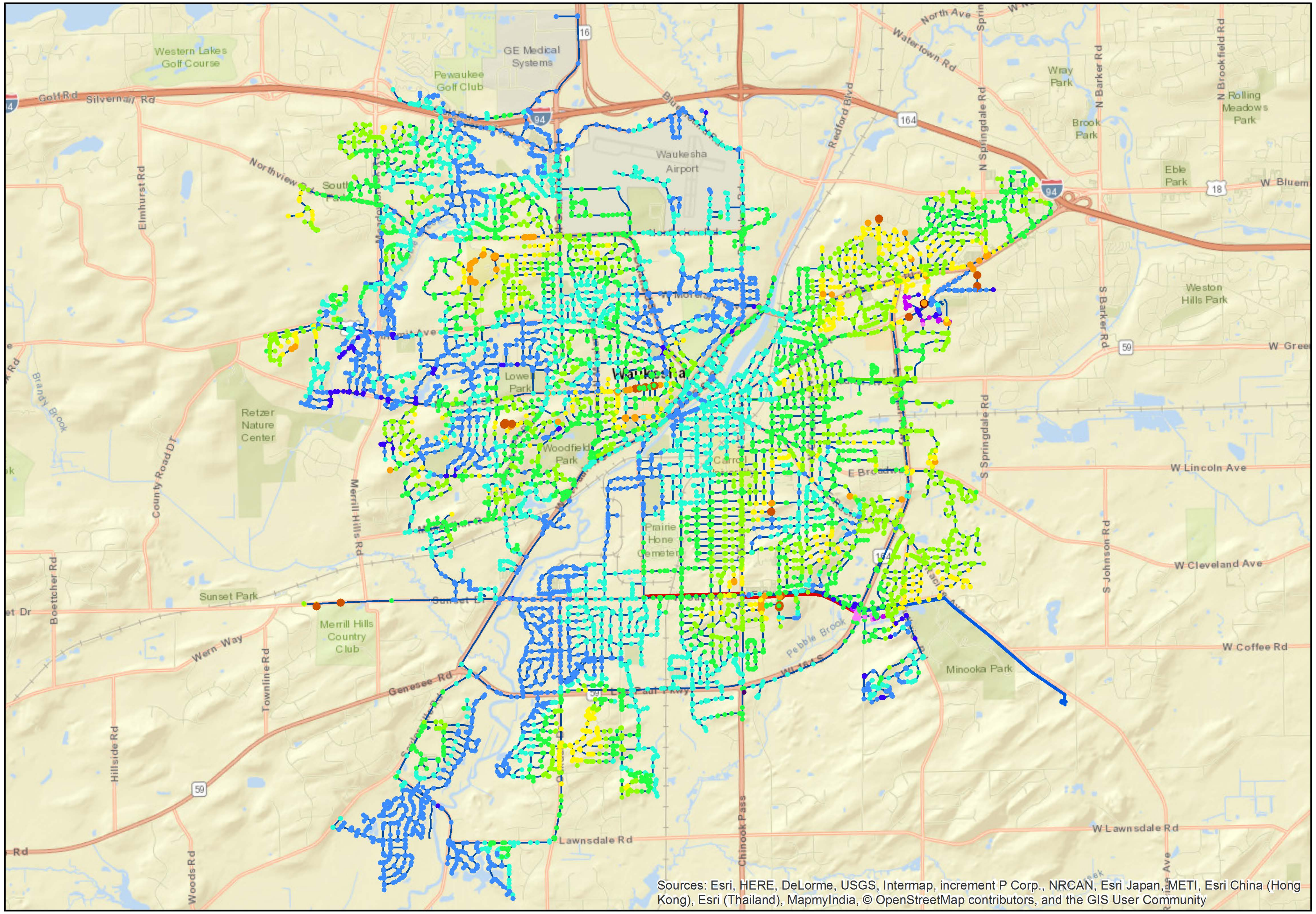
Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Future Average Day Demands
Connection Alternative 1, With Hillcrest
Date: 3/4/2018



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Minimum Pressure (psi)

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- 20.00 ~ 35.00
- 35.00 ~ 40.00
- 40.00 ~ 50.00
- 50.00 ~ 60.00
- 60.00 ~ 70.00
- 70.00 ~ 80.00
- 80.00 ~ 90.00
- 90.00 ~ 100.00
- 100.00 ~ 110.00
- 110.00 ~ 120.00
- greater than 120
- Active_Mains
- New Pipe, 16"
- New Pipe, 24"
- New Pipe, 30"

N

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1 " = 5,000 '

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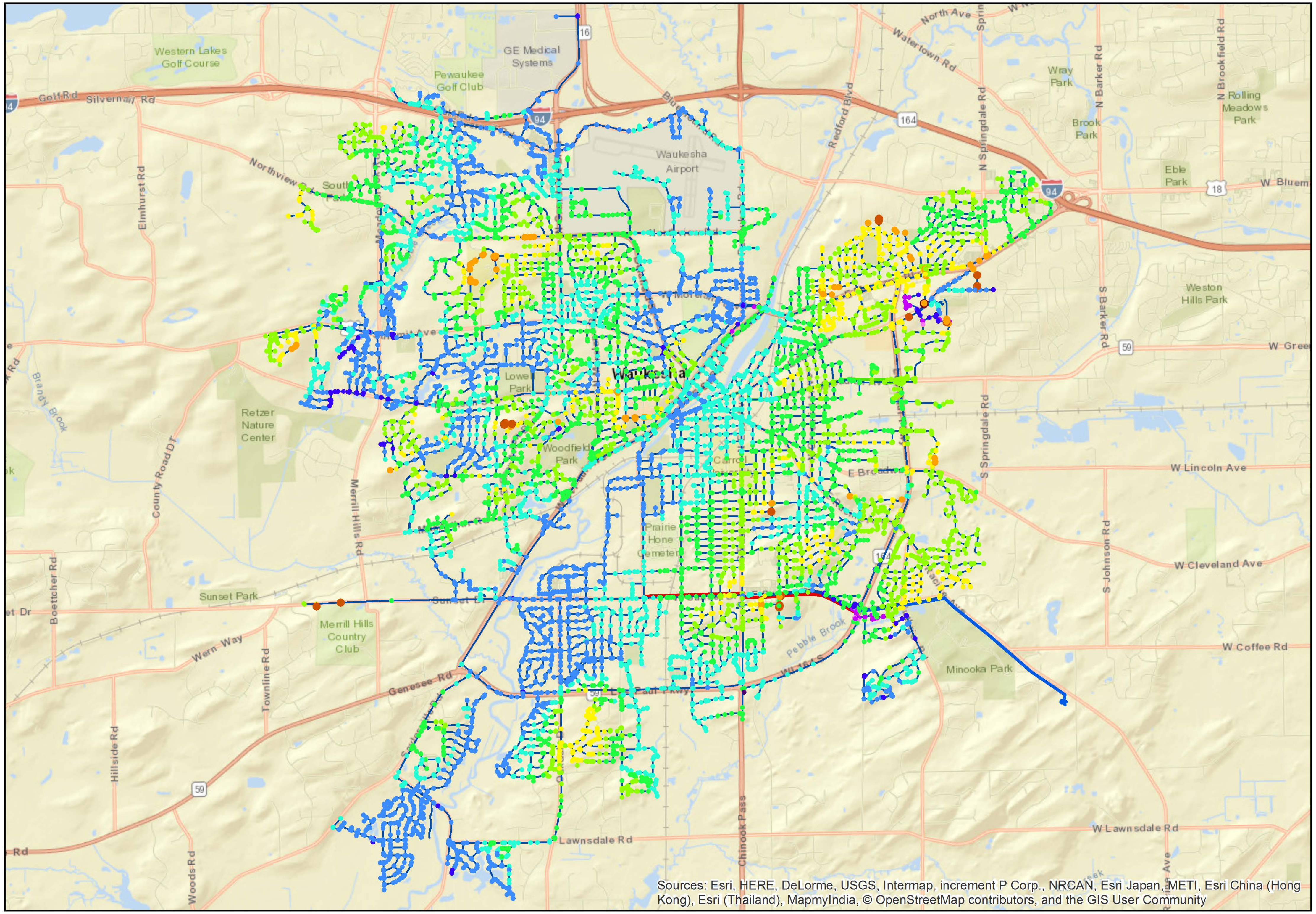
Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Existing Maximum Day Demands
Connection Alternative 1, With Hillcrest
Date: 3/4/2018



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Minimum Pressure (psi)

- less than 20.00
- 20.00 ~ 35.00
- 35.00 ~ 40.00
- 40.00 ~ 50.00
- 50.00 ~ 60.00
- 60.00 ~ 70.00
- 70.00 ~ 80.00
- 80.00 ~ 90.00
- 90.00 ~ 100.00
- 100.00 ~ 110.00
- 110.00 ~ 120.00
- greater than 120
- Active_Mains
- New Pipe, 16"
- New Pipe, 24"
- New Pipe, 30"

N

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1 " = 5,000 '

0 3,500 7,000 10,500 14,000 Feet

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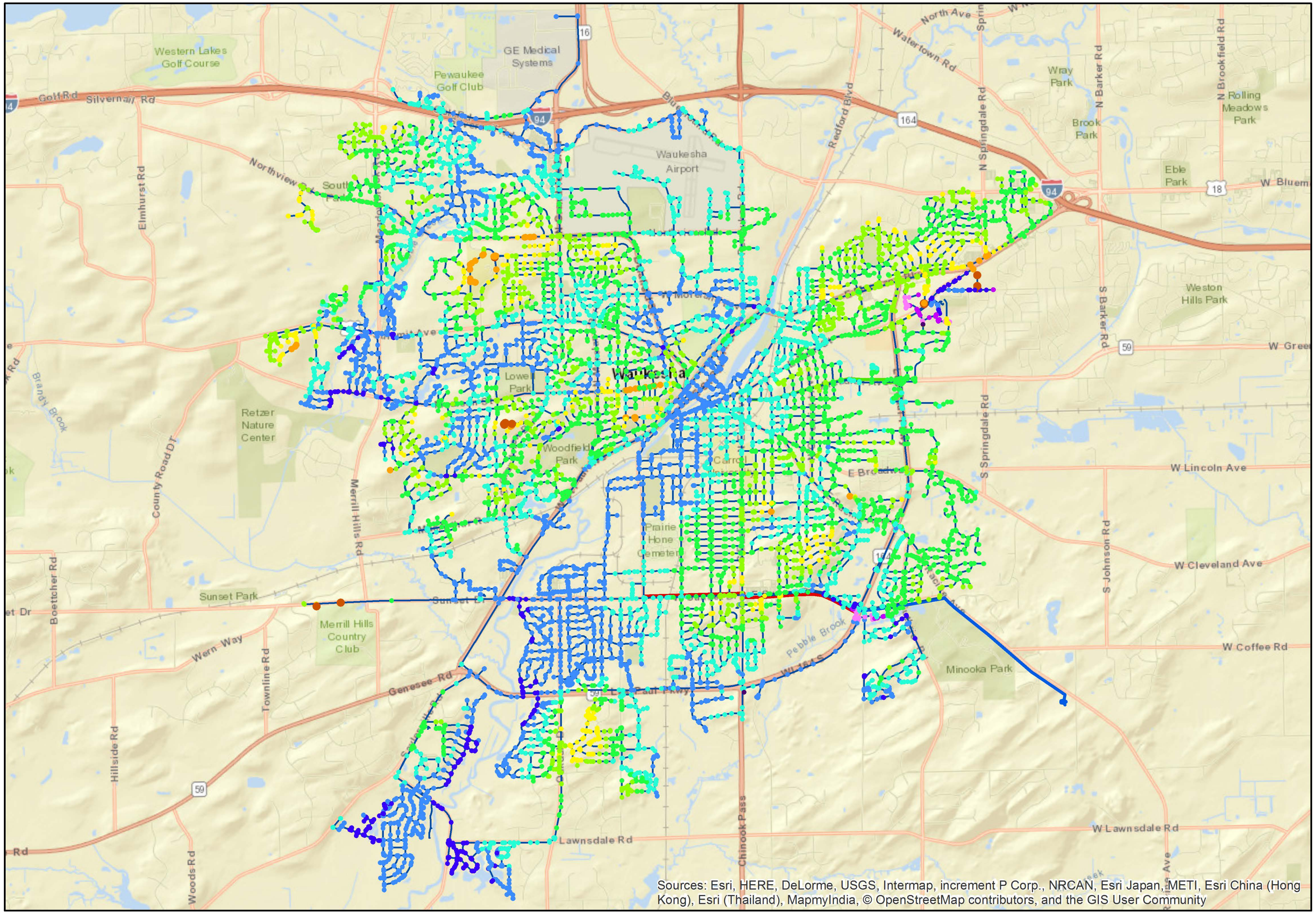

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Minimum Pressure (psi)

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- 35.00 ~ 40.00
- 40.00 ~ 50.00
- 50.00 ~ 60.00
- 60.00 ~ 70.00
- 70.00 ~ 80.00
- 80.00 ~ 90.00
- 90.00 ~ 100.00
- 100.00 ~ 110.00
- 110.00 ~ 120.00
- greater than 120
- Active_Mains
- New Pipe, 16"
- New Pipe, 24"
- New Pipe, 30"

N

DRAFT

1 " = 5,000 '

0 3,500 7,000 10,500 14,000 Feet

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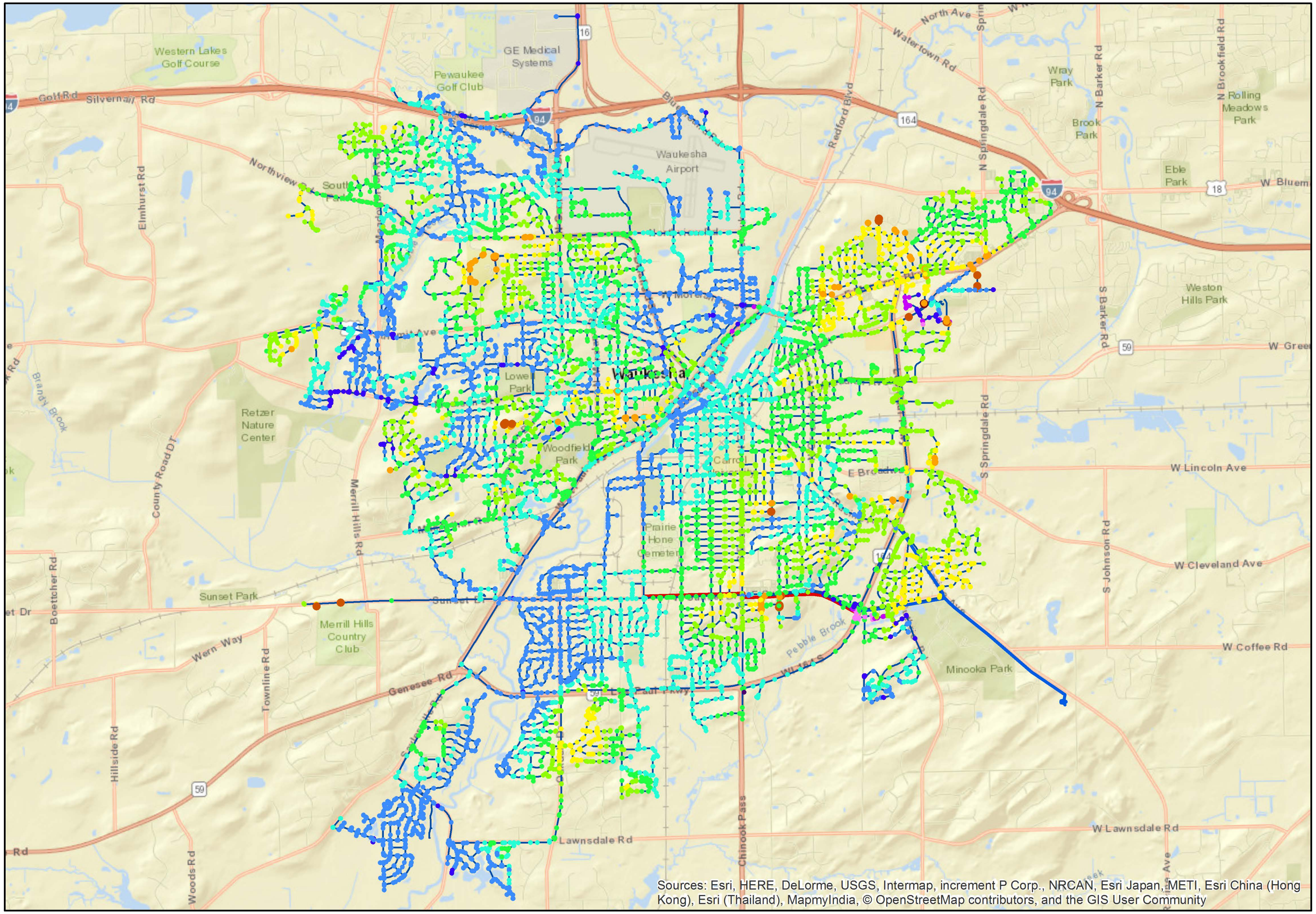
Waukesha, Wisconsin 53186

ch2m.

Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Future Maximum Day Demands
Connection Alternative 1, Without Hillcrest
Date: 3/4/2018

Plotted: 3/4/2018
Document Path: C:\Users\jhenke1\Desktop\Waukesha\GIS\MXD\Alt1_NHC_MDD.mxd



Legend

Minimum Pressure (psi)

- less than 20.00
- 20.00 ~ 35.00
- 35.00 ~ 40.00
- 40.00 ~ 50.00
- 50.00 ~ 60.00
- 60.00 ~ 70.00
- 70.00 ~ 80.00
- 80.00 ~ 90.00
- 90.00 ~ 100.00
- 100.00 ~ 110.00
- 110.00 ~ 120.00
- greater than 120
- Active_Mains
- New Pipe, 16"
- New Pipe, 24"
- New Pipe, 30"

N

1 " = 5,000 '

0 3,500 7,000 10,500 14,000 Feet

Plotted: 3/4/2018
Document Path: C:\Users\jhenke1\Desktop\Waukesha\GIS\MXD\Alt2_HC_ADD.mxd

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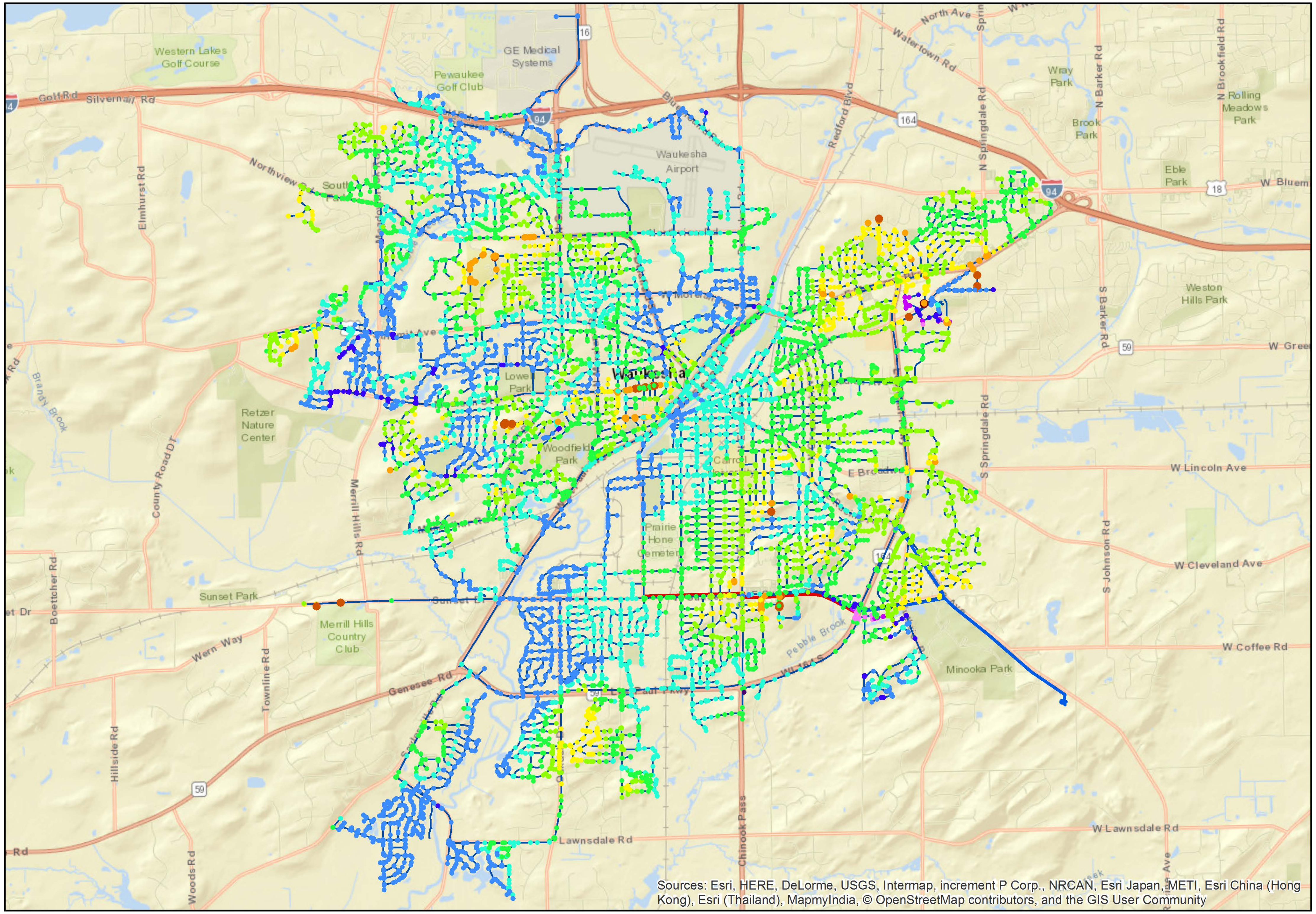
Great Lakes Water Supply Program
Minimum Pressure during Future Average Day Demands
Connection Alternative 2, With Hillcrest
Date: 3/4/2018



Legend

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- less than 20.00
- 20.00 ~ 35.00
- 35.00 ~ 40.00
- 40.00 ~ 50.00
- 50.00 ~ 60.00
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- New Pipe, 24"
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N

1 " = 5,000 '

0 3,500 7,000 10,500 14,000 Feet

Plotted: 3/4/2018
Document Path: C:\Users\jhenke1\Desktop\Waukesha\GIS\MXD\Alt2_HC_EXMDD.mxd

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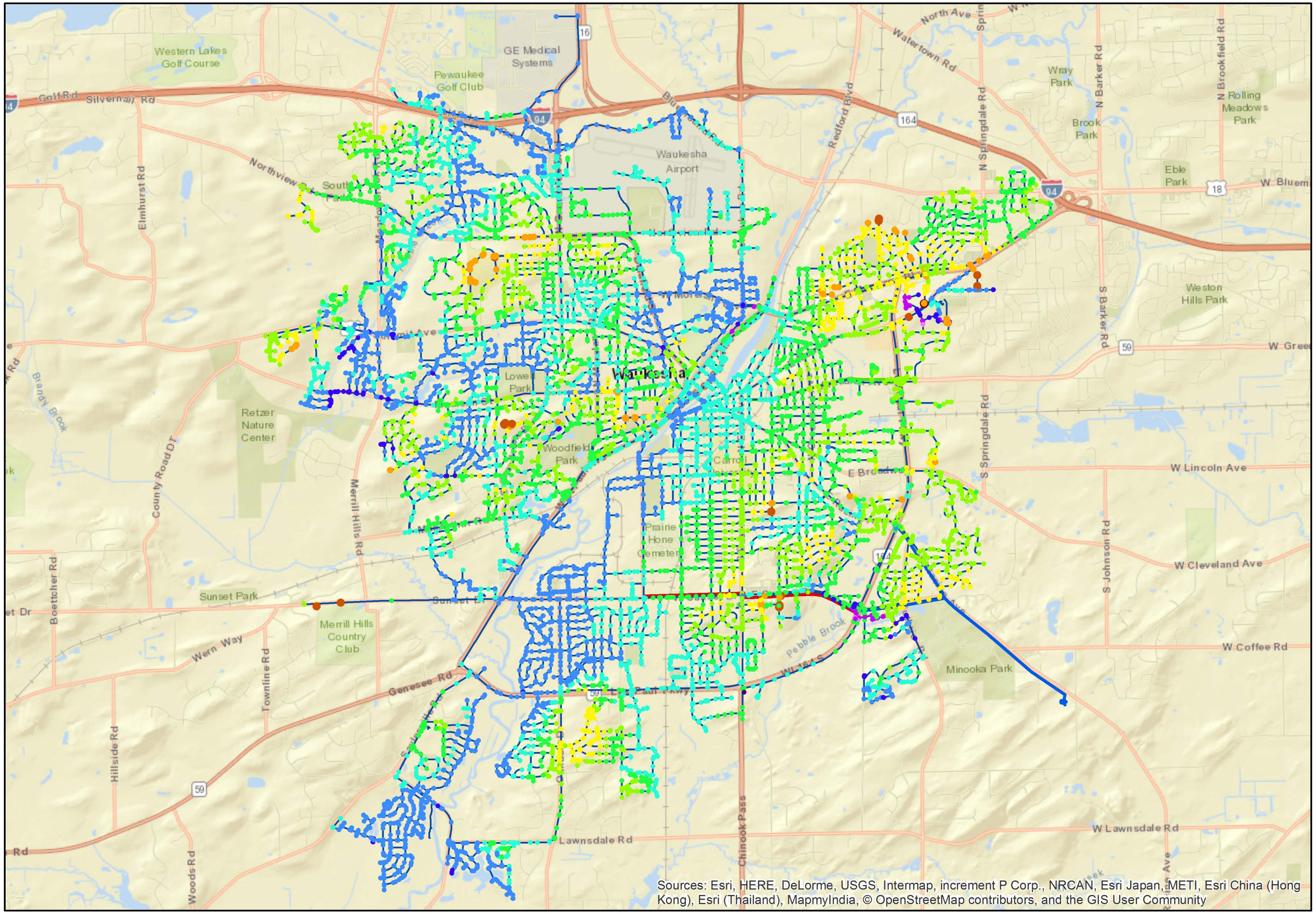
Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Existing Maximum Day Demands
Connection Alternative 2, With Hillcrest
Date: 3/4/2018



Legend

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- less than 20.00
- 20.00 ~ 35.00
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- New Pipe, 30"

N

DRAFT

1 " = 5,000 '

0 3,500 7,000 10,500 14,000 Feet

Plotted: 3/4/2018
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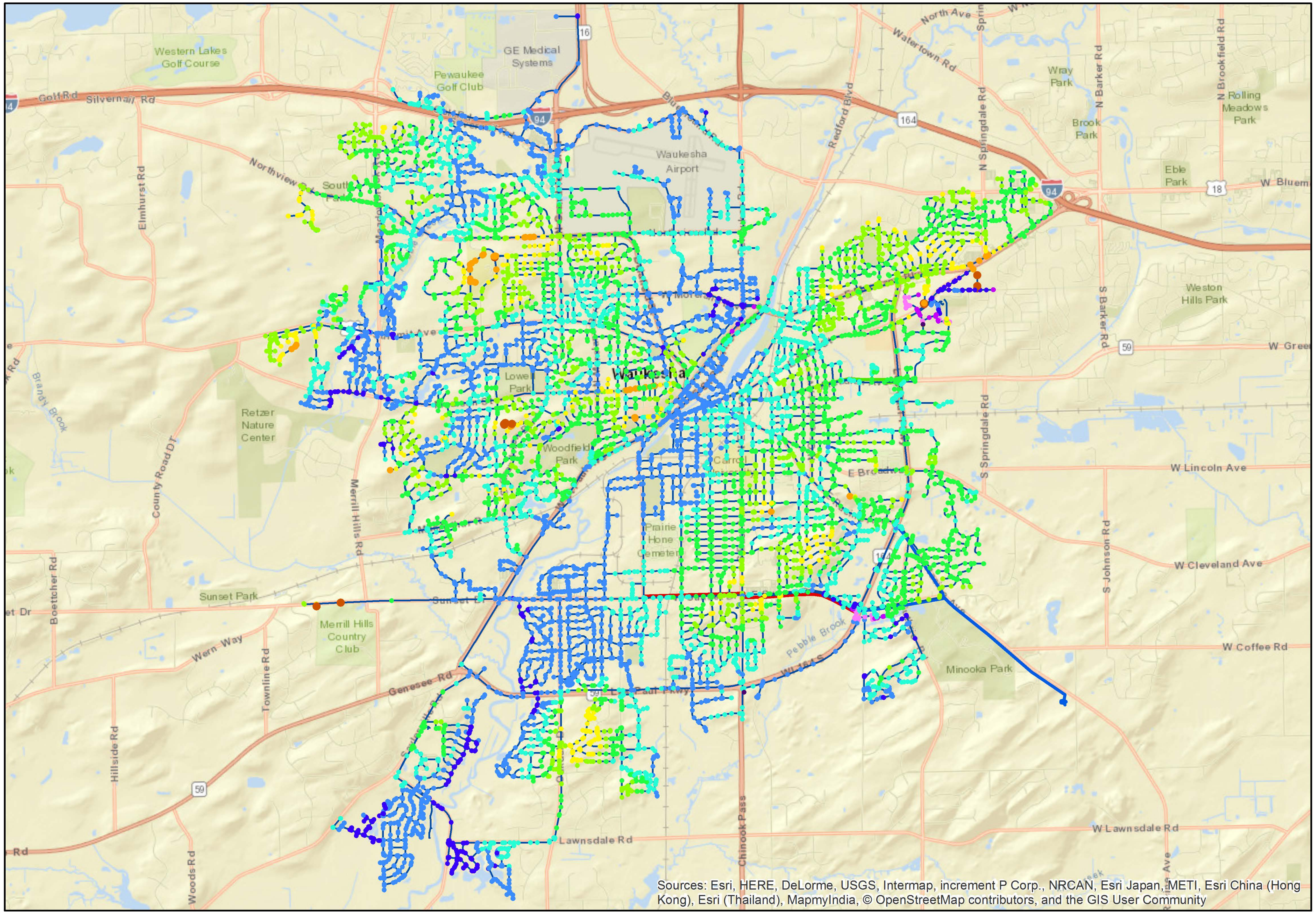
Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Future Maximum Day Demands
Connection Alternative 2, With Hillcrest
Date: 3/4/2018



Legend

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- less than 20.00
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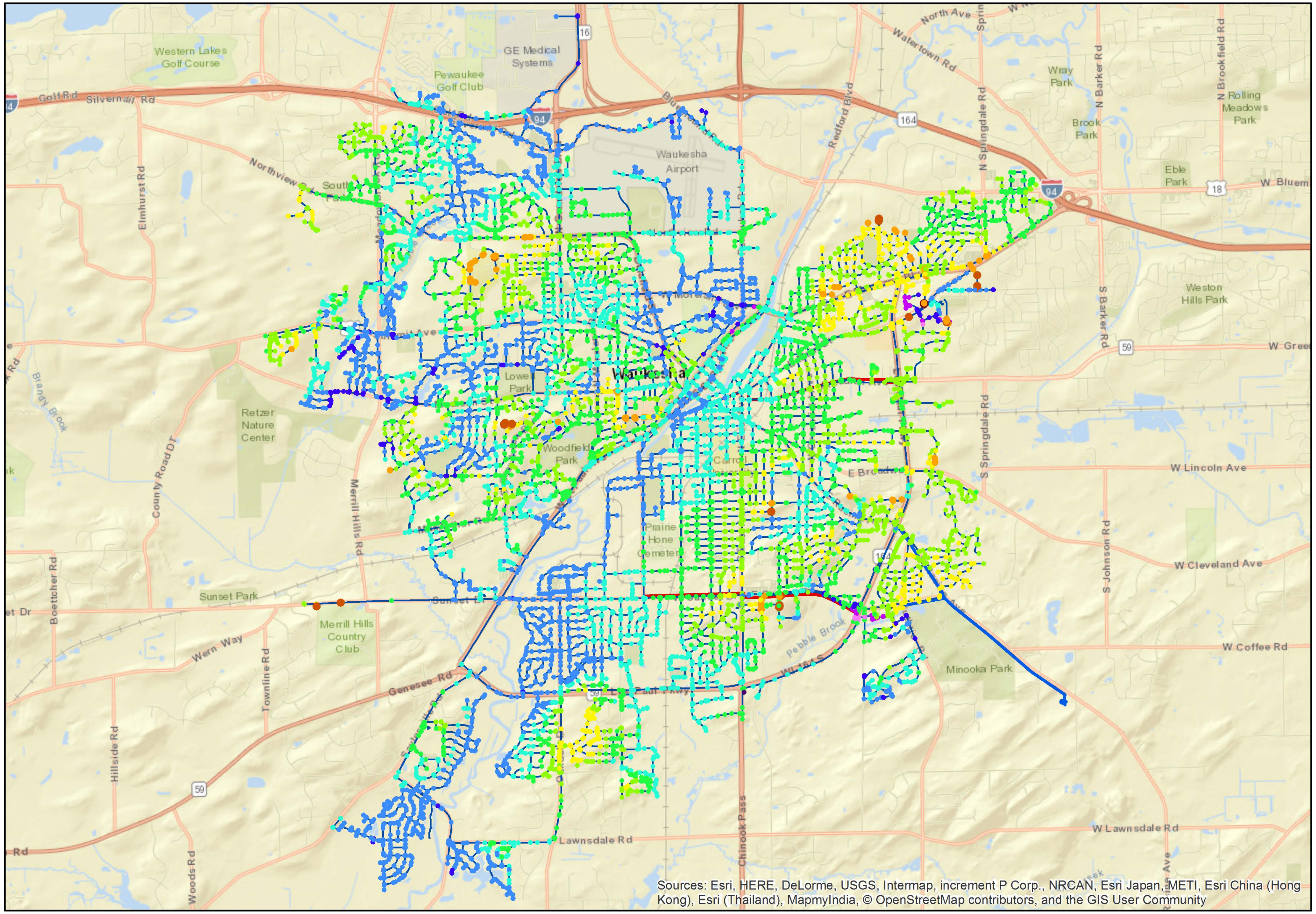
Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Future Maximum Day Demands
Connection Alternative 2, Without Hillcrest
Date: 3/4/2018

Plotted: 3/4/2018
Document Path: C:\Users\jhenke1\Desktop\Waukesha\GIS\MXD\Alt2_NHC_MDD.mxd



Legend

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DRAFT

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Plotted: 3/4/2018
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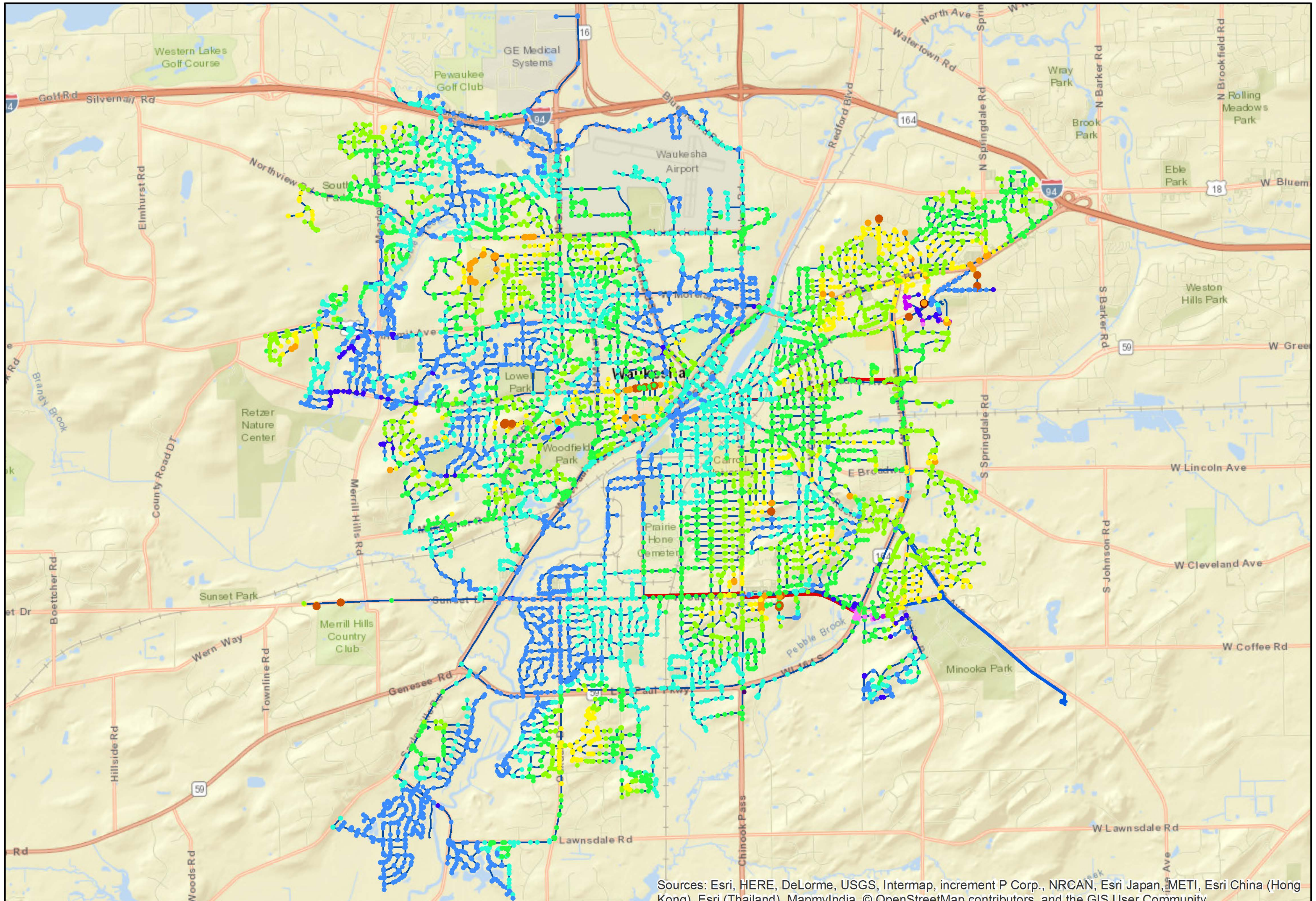
Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Future Average Day Demands
Connection Alternative 3, With Hillcrest
Date: 3/4/2018



Legend

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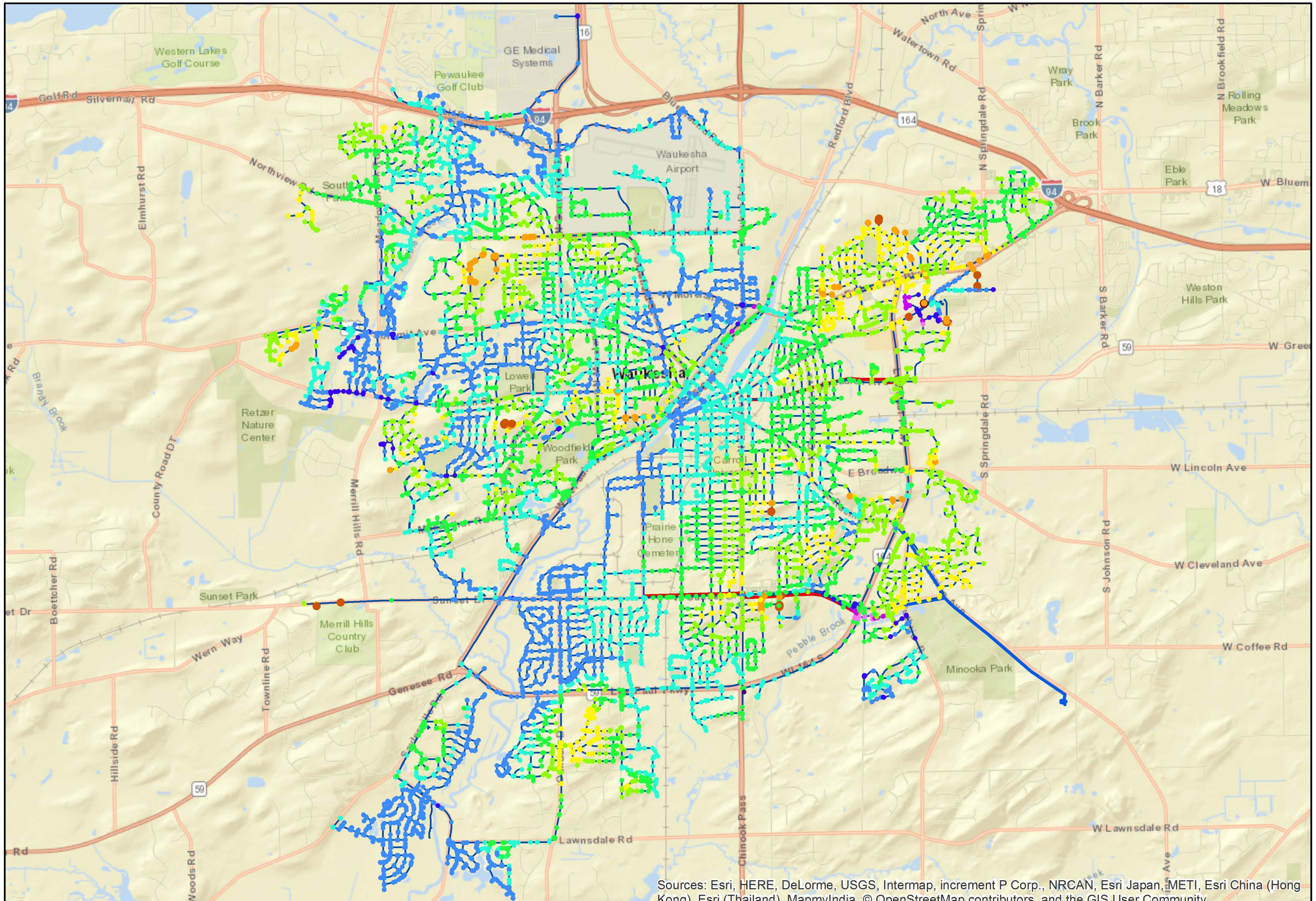
Date: 3/4/2018



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Plotted: 3/4/2018
Document Path: C:\Users\jhenke1\Desktop\Waukesha\GIS\MXD\Alt3_HC_MDD.mxd

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Minimum Pressure during Future Maximum Day Demands
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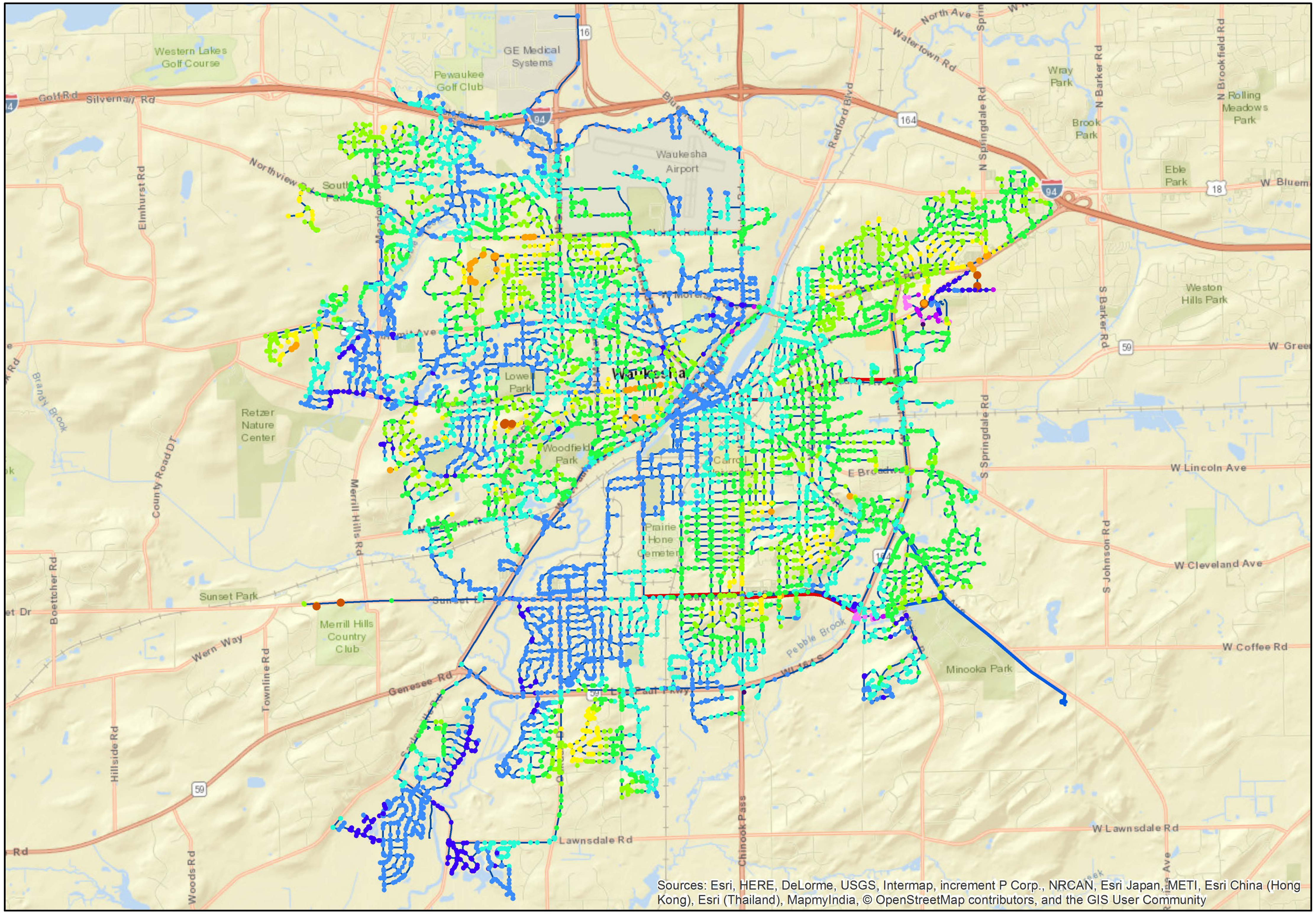

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0 3,500 7,000 10,500 14,000 Feet

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Plotted: 3/4/2018
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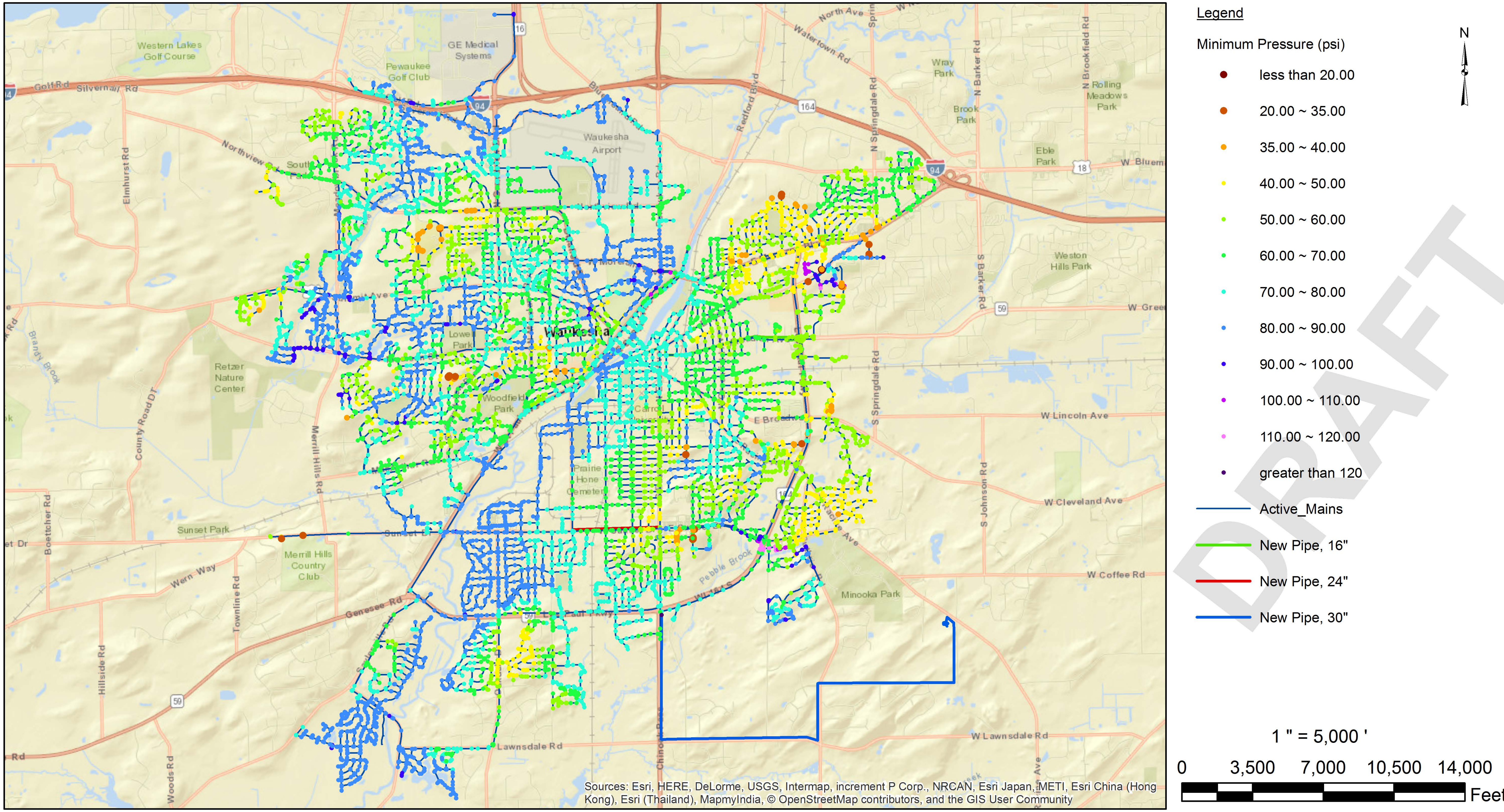
Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Future Maximum Day Demands
Connection Alternative 3, Without Hillcrest
Date: 3/4/2018



Plotted: 3/4/2018
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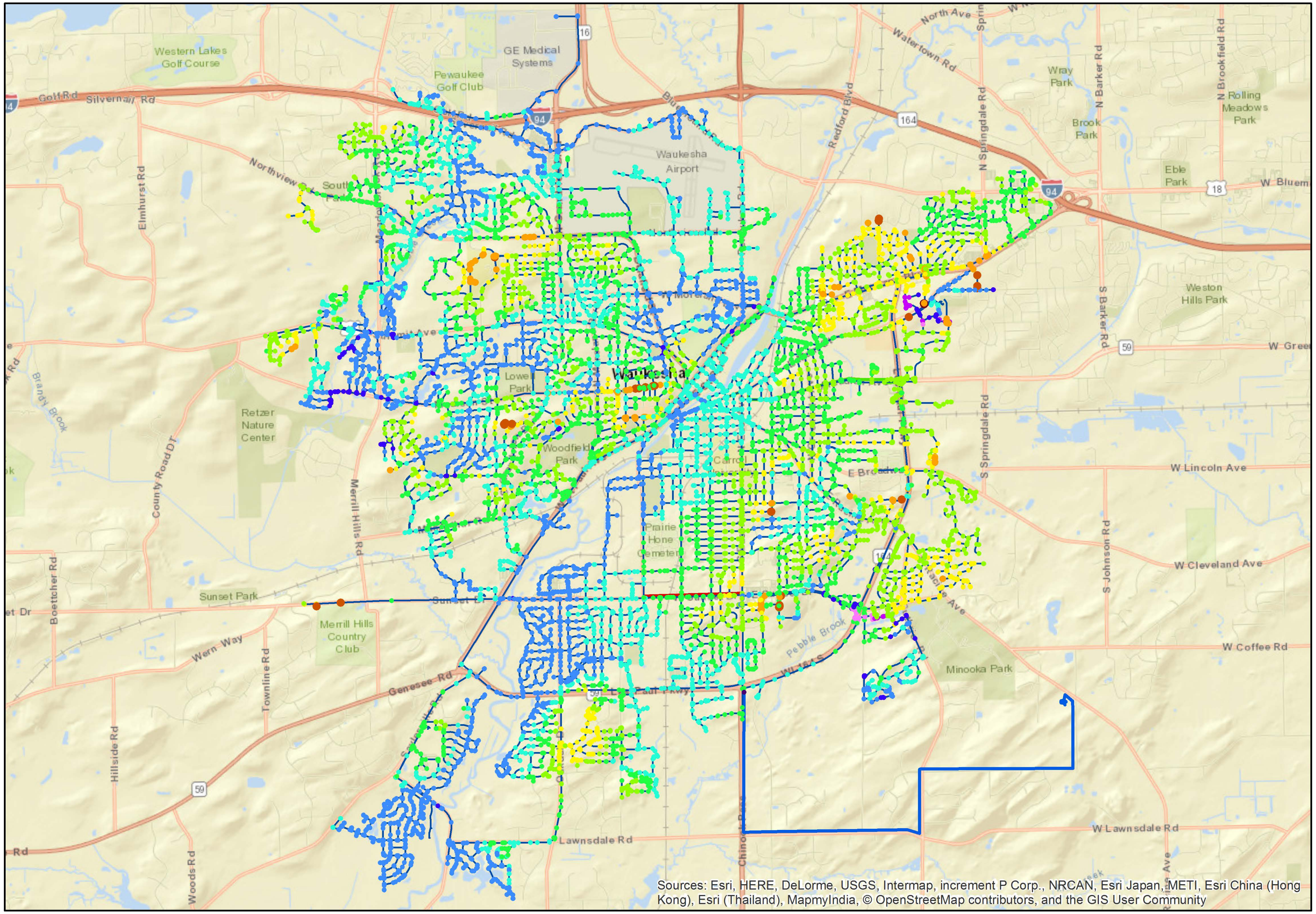
Great Lakes Water Supply Program
Minimum Pressure during Future Average Day Demands
Connection Alternative 4, With Hillcrest
Date: 3/4/2018



Legend

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N

1 " = 5,000 '

0 3,500 7,000 10,500 14,000 Feet

DRAFT

Plotted: 3/4/2018
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Minimum Pressure during Existing Maximum Day Demands
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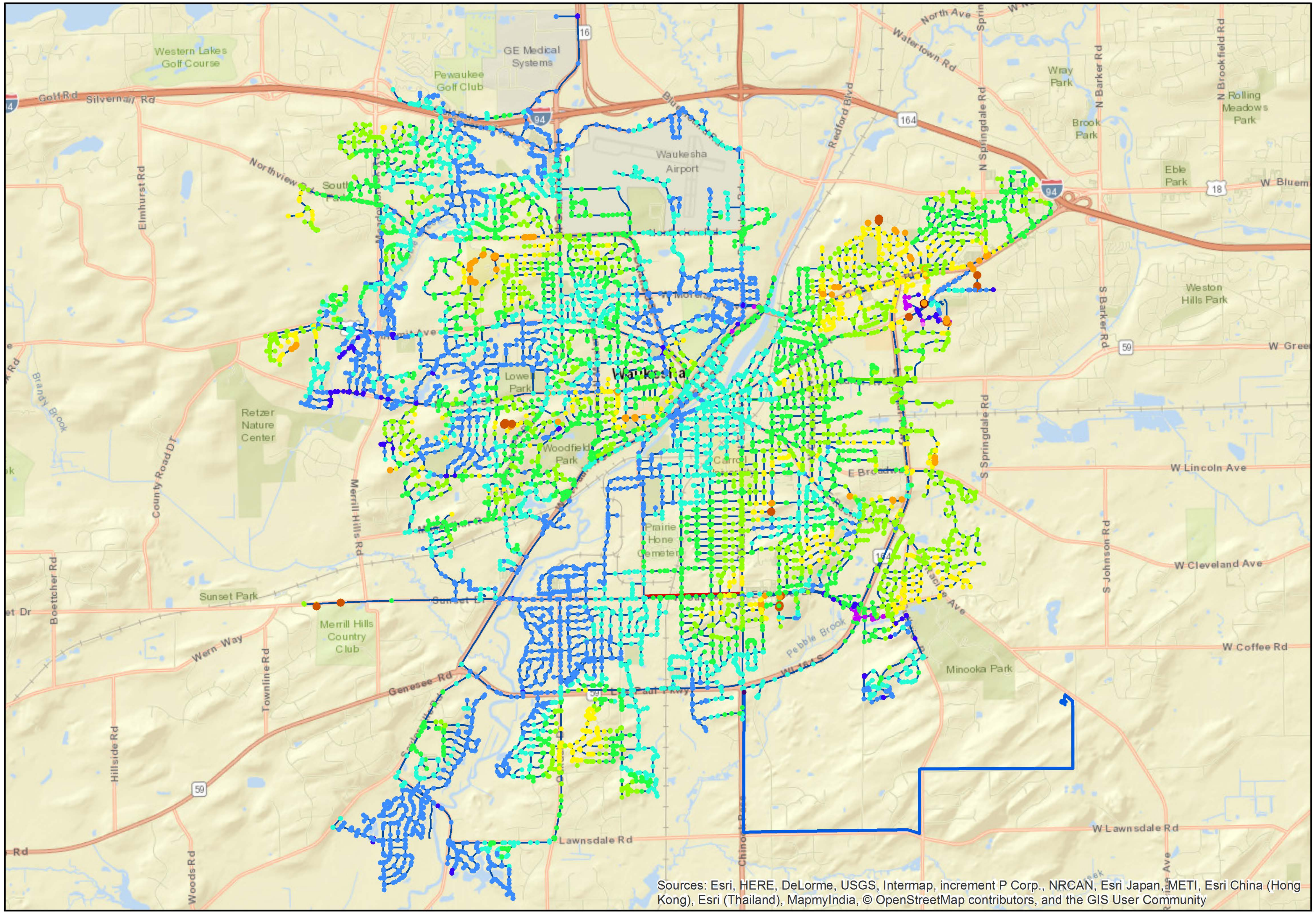
Date: 3/4/2018



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DRAFT

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Plotted: 3/4/2018
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Waukesha Water Utility
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Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Future Maximum Day Demands
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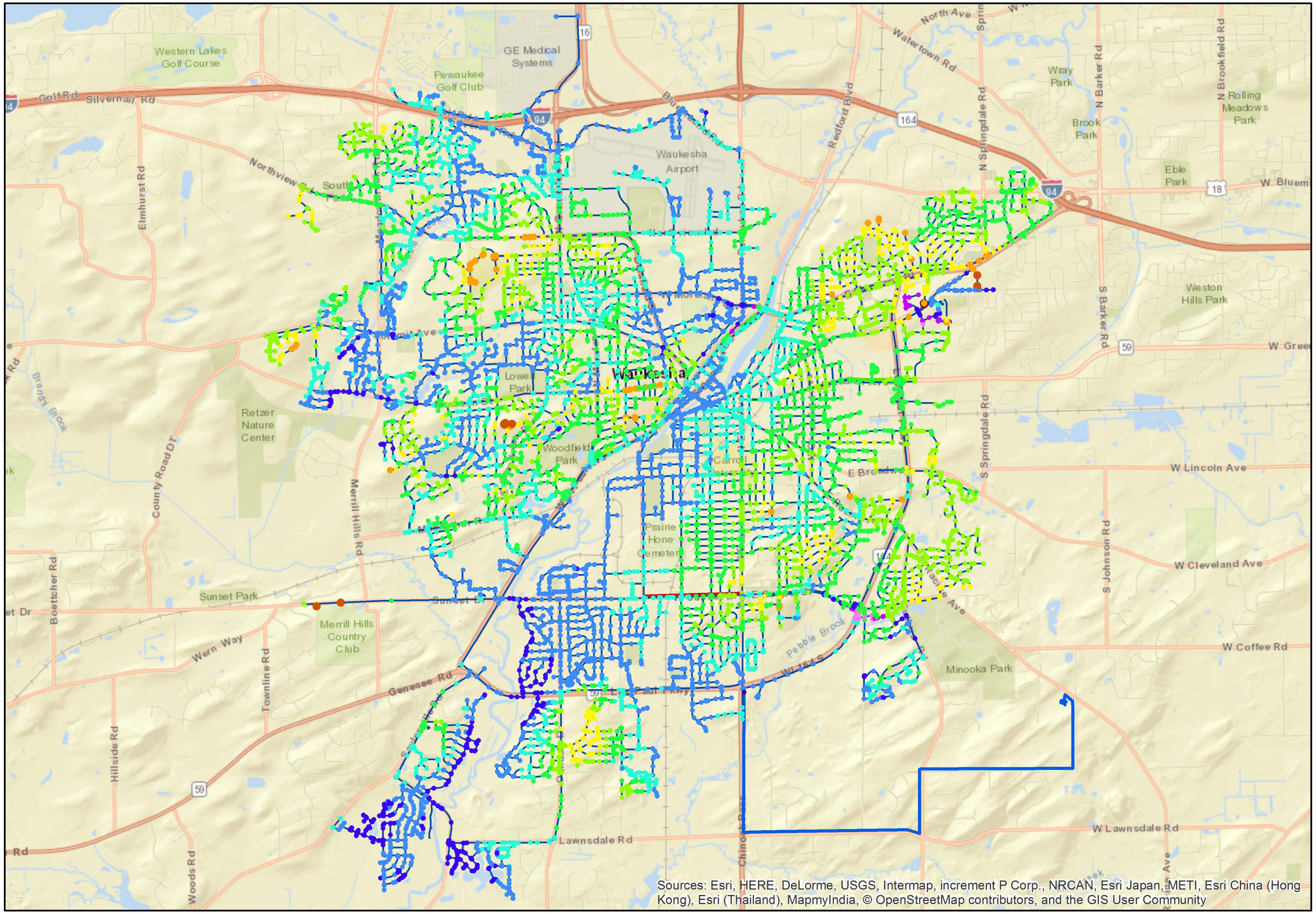
Date: 3/4/2018



Legend

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- less than 20.00
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N

DRAFT

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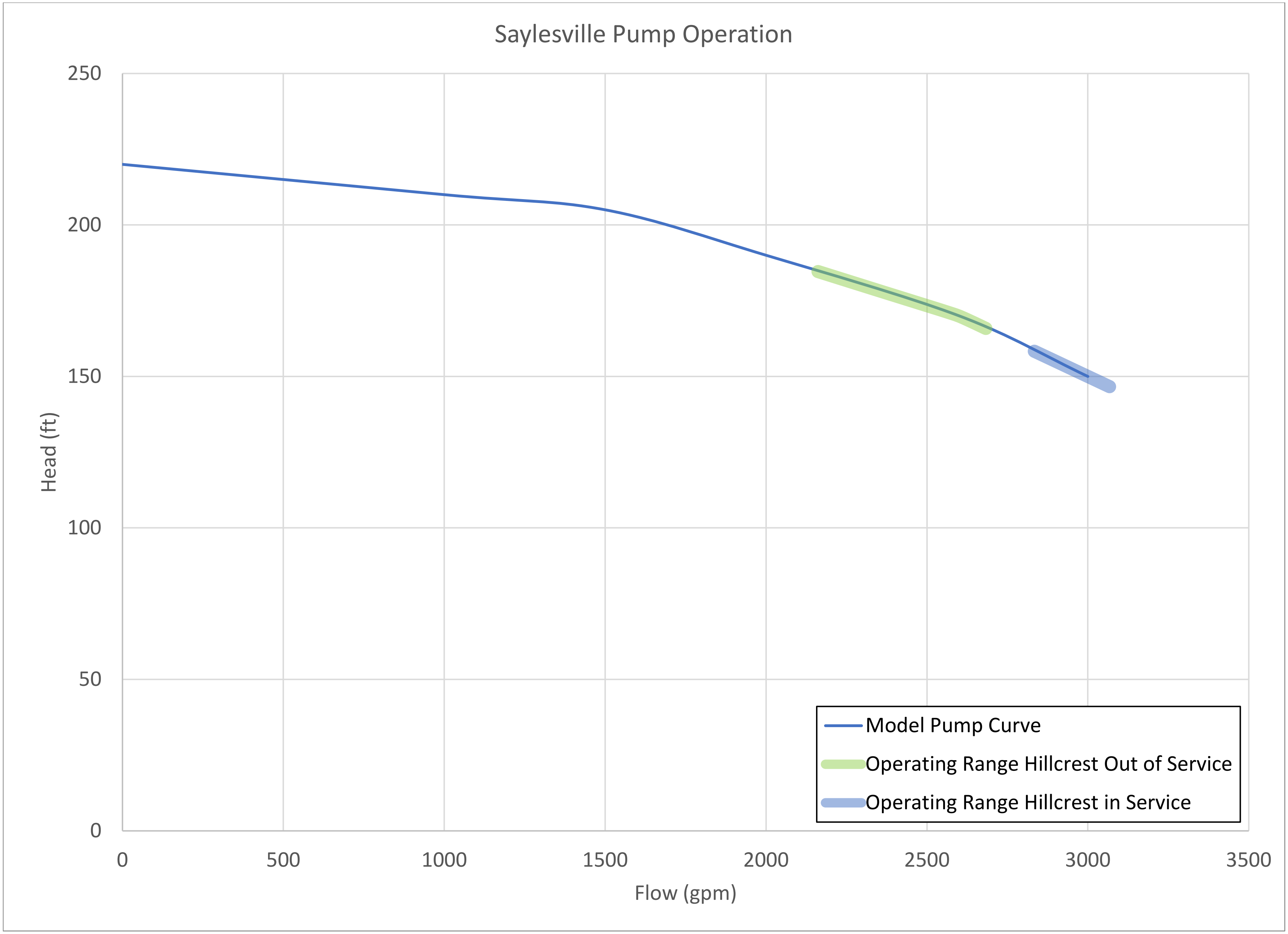
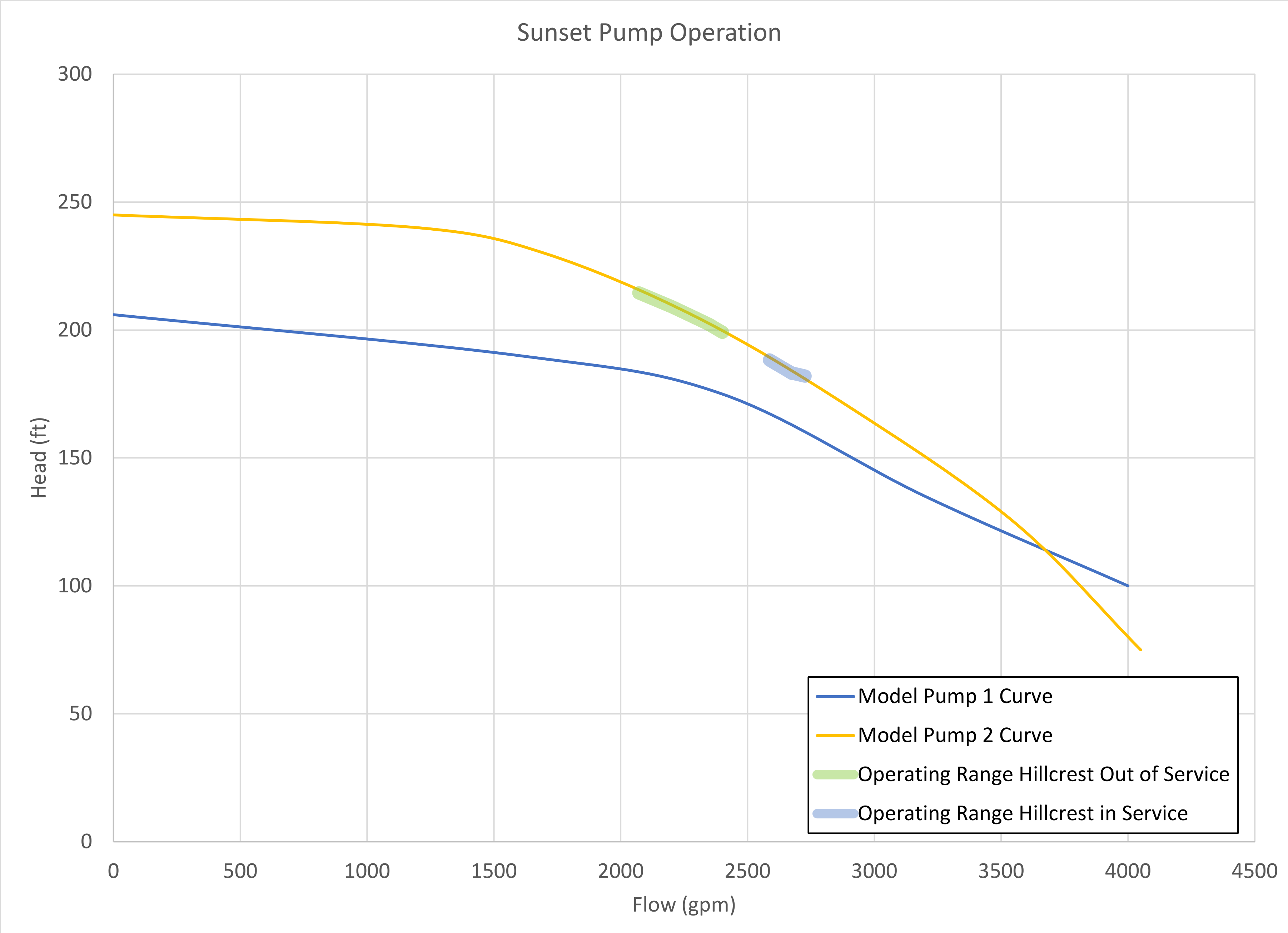
Waukesha, Wisconsin
Great Lakes Water Supply Program
Minimum Pressure during Future Maximum Day Demands
Connection Alternative 4, Without Hillcrest
Date: 3/4/2018

Plotted: 3/4/2018
Document Path: C:\Users\jhenke1\Desktop\Waukesha\GIS\MXD\Alt4_NHC_MDD.mxd

Appendix B – Pump Operation Curves



Saylesville Pump Operation
250
200
150
100
50
0
Head (ft)
0
500
1000
1500
2000
2500
3000
3500
Flow (gpm)
Model Pump Curve
Operating Range Hillcrest Out of Service
Operating Range Hillcrest in Service


Sunset Pump Operation
Head (ft)
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Flow (gpm)
Model Pump 1 Curve
Model Pump 2 Curve
Operating Range Hillcrest Out of Service
Operating Range Hillcrest in Service

GREELEY AND HANSEN

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